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A UNIFORM METHOD OF ANALYSIS FOR SQUARE LATTICE EXPERIMENTS[1]

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Among incomplete block experimental designs for the testing of a large number of varieties the square lattice is one of the most useful. Three square lattice designs are in common use. These are the simple lattice, the triple lattice, and the balanced lattice. Methods of analysis for these have been given by various writers in addition to Yates (2,3,4,5,6) who was responsible for their development. It does not appear to be generally recognized that there are other types such as the quadruple lattice that are possible in this series and that a uniform method of analysis may be used for the entire series of square lattice designs beginning with the simple lattice and ending with the balanced lattice whenever the latter is possible with a given number of varieties. The purpose of this paper is to present such a uniform method of analysis and to point out the uses for types such as the quadruple and quintuple lattice. Recently, the author has received the unpublished manuscript of *Experimental Designs* by W. G. Cochran and Gertrude M. Cox in which similar methods are outlined.

FUNDAMENTALS OF THE SQUARE LATTICE DESIGN

Numbers representing the varieties to be tested in a square lattice experiment can be set up in the form of a square and it is convenient to use two figure numbers in which the first digit represents the row of the square and the second digit the column of the square. Thus for p^2 varieties we will have a square as follows. This square can be used as a starting point for a description of all square lattice designs.

$$\begin{array}{cccccc} 11 & 12 & 13 & \ldots & 1p \\ 21 & 22 & 23 & \ldots & 2p \\ \cdot & \cdot & \cdot & & \cdot \\ p1 & p2 & p3 & \ldots & pp \end{array}$$

The Simple Lattice

In the first replicate we place the varieties together in blocks that occur in the rows of the square, and in the second replicate those that occur in the columns. We require therefore a minimum of 2 replicates. If more are desired the same arrangement is repeated as many times as is necessary in order to obtain sufficient accuracy. The replicates in which

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the blocks are made up from the rows of the square can be referred to conveniently as the A group and those from the columns as the B group. The arrangement in the field is to keep all the blocks of one replicate in as compact a form as possible but to randomize the positions of the blocks within the replicates and of the varieties within the blocks.

The Triple Lattice

This is similar to the simple lattice except that a third group is added by making up the blocks from the varieties that occur in the diagonals of the square. For example, with 25 varieties the original square is as follows together with another square in which the varieties in the rows occur in the diagonals of the original square.

Original Square					*Square in which Rows are formed from Diagonals of Original*				
11	12	13	14	15	11	22	33	44	55
21	22	23	24	25	21	32	43	54	15
31	32	33	34	35	31	42	53	14	25
41	42	43	44	45	41	52	13	24	35
51	52	53	54	55	51	12	23	34	45

The third group may be referred to as group C. The minimum number of replicates is 3 but by repeating all 3 groups we can have 6, 9, or 12 replicates, or any other multiple of 3. As in the simple lattice the replications are arranged as compactly as possible and the blocks randomized within the replicates and the varieties within the blocks.

The Quadruple and Other Partially Balanced Square Lattice Designs

It will be obvious to the reader that a quadruple lattice will result merely from forming another group of blocks, and provided that the orthogonal groups can be formed the series can be continued. However, there are some complications and restrictions in the forming of further groups. In the first place, for certain numbers of varieties such as 36, it is impossible to form more than 3 groups that are orthogonal to each other. On examining groups A, B, and C of a triple lattice it will be noted that the varieties making up any one block are such that one variety is taken from each block in another group. For example, in group C the first row is 11, 22, 33, 44, 55. The first figure of the 2-digit numbers shows that each variety comes from a different row of the original square, and the second figure shows that each variety comes from a different column of the original square. This is what is meant when we say that any one group is orthogonal to all of the other groups. The meaning in terms of the analysis is that the variation in the results for any one group of blocks is independent of the variation in any other group of blocks.

In the second place, the mechanical method we have used for the formation of group C for the triple lattice can be carried forward for the formation of futher groups only if the number of varieties is the square of a prime number. It can be used therefore for 25, 49, and 121 varieties

but not for 64, 81, or 100. When the number of varieties is the square of a prime number the method is to write the numbers in the rows of the square for group D that occur in the diagonals of the square for group C. Group E can then be written from the square for group D in a similar manner. We can continue until we have written out $p + 1$ groups. No further orthogonal groups can be obtained. However, if we use $p + 1$ groups our design becomes a Balanced Lattice and possesses properties which justify our placing it in a separate class. If the number of varieties is not the square of a prime number such as 64, 81, or 100, we must make use of a device known as a completely orthogonalized square for writing out groups other than the first two that we have designated by the letters A and B. A completely orthogonalized 4×4 square is given below which will be used to illustrate the method of writing out the groups for 16 varieties.

Completely Orthogonalized 4 × 4 Square

111	234	342	423
222	143	431	314
333	412	124	241
444	321	213	132

We note first that for a 4×4 square the A and B groups can be written out from the rows and columns of the square without difficulty. The figures in the orthogonalized square are given therefore for groups C, D, and E only. The first digit in each 3-figure number gives us group C as follows. If the orthogonalized square were superimposed on the square of variety numbers the figure 1 would correspond to varieties 11, 22, 33, 44. This would be the first row of the square for group C. The figure 2 would correspond with the varieties 21, 12, 43, 34, and this would be the second row of the square. Finally we would have the square for group C as follows:

11	22	33	44
21	12	43	34
31	42	13	24
41	32	23	14

The second digit in the 3-figure numbers would be used in a similar manner in order to obtain group D, and the third digit to obtain group E. A complete set of the orthogonalized squares so far available are given in *Statistical Tables* by R. A. Fisher and F. Yates (1).

The Balanced Lattice

The method of laying out a balanced lattice experiment will be obvious from the above discussion. We should be careful to note however, that although a partially balanced lattice can be designed with any number of replicates greater than 1, the number of replicates required in order to obtain complete balance is $p + 1$. Thus for 64 varieties we require 9

replications in order to obtain complete balance. This characteristic confines the use of the balanced lattice to rather narrow limits. It is ideal for 25 varieties as ordinarily the experimenter will wish to use about 6 replications. It is also satisfactory for 49 varieties if the material is sufficiently variable to require the use of 8 replications. The advantages of the balanced lattice are that all comparisons between varieties are made with equal accuracy and the method of analysis is somewhat simpler than for the partially balanced lattice. In the latter, varieties that occur together in the same block are compared somewhat more accurately than those that do not occur together in the same block. This difference is greatest in the simple lattice and decreases with the number of groups used. Even for the simple lattice however, the difference in the accuracy of the comparison of varieties in the same and in different blocks is not great enough to be of much concern. The appropriate standard errors for each type of comparison can be worked out if necessary but in general it is satisfactory to use a mean standard error which can be applied to all comparisons without appreciable error. The greater simplicity of the analysis of the balanced lattice designs is not an important factor as the additional time required is quite small and is negligible in proportion to the total amount of time spent in operating the experiment.

METHODS OF ANALYSIS—SQUARE LATTICE EXPERIMENTS

The Partially Balanced Lattice

Although different methods of analysis are usually presented for simple and triple lattice experiments, the following methods will be found to apply to any type of partially balanced lattice and with a few simplifications will also apply to the balanced lattice.

The analysis of the results of a lattice experiment should be kept in mind when the field plans are made. All information relevant to the design should either be entered in the field record or should be kept on file where it will be readily available. As an illustration of the method we shall use the actual results from a quadruple lattice with 25 varieties in 4 replications. The method used can be adapted easily to an example such as a simple lattice with 4 or 6 replications by the introduction of certain modifications that will be described.

A useful first step in the analysis of an incomplete block experiment of the lattice type is to make a preliminary analysis of variance assuming that the test has been laid out in randomized blocks. This does not result in an appreciable loss of time as all the sums of squares will be required in the more complete analysis. If the preliminary analysis shows that the variety differences are significant it will not be necessary to make the more accurate test described later, as the significance of these differences will either be increased or will remain at the same level when the error control due to the blocks has been taken into consideration.

The next step in the analysis is to collect the individual plot yields as in Table 1, re-arranging the variety numbers in a systematic manner corresponding to the squares as originally written out for the groups A, B, C, and D, and writing down the total of each block represented by b. Space is left for entering the values designated by y and $y - rb$, where r

is the number of replications. The variety totals T_v where v represents a variety number, are then obtained and preferably set up in the form of a square as in Table 2, as this will facilitate the determination of the values of y to be entered in Table 1. The first value of y in Table 1 is 575.5 which is the sum of the totals of the varieties that appear in that block. This is the first row total of Table 2. The remaining values of y in replicate 1 are the remaining row totals of Table 2. In replicate 2 the y's are the column totals of Table 2. In replicate 3 we get y from the diagonal totals of Table 2 taking the first diagonal as the one beginning with variety 11. To get y for replicate 4 we can either re-write the variety totals in the diagonals of Table 2 in the rows of a new table and then take the diagonal totals from this table, or we can merely sum the variety totals as indicated by the variety numbers in the corresponding block. For example, in the first block of group D we sum the totals of varieties 11, 32, 53, 24, and 45, and so forth for any other block. This method is emphasized because in an experiment made up from an orthogonalized square for which the number of varieties is not the square of a prime number, it is the only method of obtaining the values of y for all replicates except those containing groups A and B for which y can always be taken from the rows and columns of the square of variety totals.

The procedure described above for obtaining values of y and the block totals b is the same for all partially balanced lattice designs regardless of the number of groups. It is merely a matter of obtaining the block totals and placing opposite each block total the sum of the totals of the varieties occurring in that block.

In the next stage of the calculations we obtain an analysis of variance in which the variance for blocks is determined in such a way that the effect of varieties is eliminated. Obviously, the variance of the block totals without correction will not represent pure block effect as the varieties that occur in them are not all the same. In order to obtain the corrected block sum of squares there are two procedures that can be followed. The first is to calculate the sum of squares within replicates for the values of $y - rb$, where r represents the number of groups and the number of replicates in the experiment. If we represent $\Sigma(y - rb)$ for one replicate by S, the required sum of squares will be

$$\text{Blocks (SS)} = \frac{\Sigma(y - rb)^2}{pr(r - 1)} - \frac{\Sigma(S^2)}{p^2r(r - 1)} \qquad 1$$

A second method is to first calculate for each variety the values that we shall represent by W_v. These will be required later in making the corrections to the variety totals. For any one variety

$$W_v = \Sigma(y_v - rb_v) \qquad 2$$

where the summation extends over the r replicates or groups and the subscripts for y and b indicate that in each replicate we take the value of $y - rb$ that corresponds to a given variety v. As an example we have from Table 1

$$W_{23} = -173.9 - 153.2 + 262.4 + 63.0 = -1.7$$

The sum of squares for blocks eliminating varieties is then given by

$$\text{Blocks (SS)} = \frac{\Sigma(W_v^2)}{r(r-1)p^2} \tag{3}$$

In choosing between the two methods of obtaining the block sums of squares we should note that the volume of work will depend on the number of values to be squared and the number of operations to be performed. formula 1 requires that we square $r(\mathrm{p}+1)$ values, perform 2 divisions and 1 subtraction. For formula 2 we have to square p^2 values but there is only 1 division and no subtractions. The second method is the most straightforward and is recommended for all cases except where r is small in proportion to p. It has the additional advantage that it is the same procedure as is followed for obtaining the block sum of squares in analysing a balanced lattice.

The sums of squares for replicates, varieties, and total are taken from the preliminary analysis. The sum of squares for intrablock error is then obtained by the subtraction of replicates, blocks and varieties from the total. We can now set up an analysis of variance according to the following scheme.

	DF	Mean Square
Replicates	$r-1$	
Blocks, eliminating Varieties	$r(p-1)$	B
Varieties	p^2-1	
Intrablock error	$(p-1)(rp-p-1)$	E
Total	rp^2-1	

From the above analysis we note the relative values of B and E. If B is not greater than E we can assume that error control by means of the blocks has not been efficient and we will discard the more elaborate analysis and carry on as if the experiment had been laid out in randomized blocks. This occurs only in exceptional cases. If B is smaller than E it is justifiable to assume that the situation is the same as if B is equal to E, although if there is a considerable discrepancy in this direction one would be inclined to look for errors, either in the computations or in the handling of the experiment. Generally, we find that B is at least 2 or 3 times as great as E and we proceed as follows, to obtain the corrected variety means and the standard error of differences between two variety means. The first step is to calculate the coefficient λ as follows

$$\lambda = \frac{B-E}{B} \tag{4}$$

Then a corrected variety total is

$$rt_v = T_v + \left\{\frac{\lambda}{(r-1)p}\right\} \mathrm{W}_v \tag{5}$$

As pointed out above, in a partially balanced experiment, all comparisons are not made with equal precision; that is, varieties that occur in the same block will be tested more accurately than varieties that do not

occur in the same block. For varieties occurring in the same block the variance of a difference between two means is

$$V_e = \frac{2E}{r}\left\{1 + \frac{B - E}{pB}\right\} = \frac{2E}{r}\left\{1 + \frac{\lambda}{p}\right\} \qquad 6$$

For varieties not occurring in the same block the variance is

$$V_d = \frac{2E}{r}\left\{1 + \left(\frac{r}{r-1}\right)\frac{B - E}{pB}\right\} = \frac{2E}{r}\left\{1 + \left(\frac{r}{r-1}\right)\frac{\lambda}{p}\right\} \qquad 7$$

A mean variance for all comparisons which can be used without appreciable error is

$$V_m = \frac{2E}{r}\left\{1 + \left(\frac{r}{r-1}\right)\frac{B - E}{(p+1)B}\right\}\frac{2E}{r}\left\{1 + \frac{rp}{(p+1)(r-1)}\left(\frac{\lambda}{p}\right)\right\} \qquad 8$$

Finally, if it is considered sufficiently important, the variety sum of squares can be adjusted in order to obtain a variety variance which can be tested against the intrablock error. We first calculate the block variance without adjusting for the effect of varieties. In other words this is calculated directly from the block totals. Representing this sum of squares by B_u and the block sum of squares as calculated above after eliminating the effect of varieties by B_a, the adjustment to the variety sum of squares is given by

$$-\lambda\left\{\left(\frac{rB}{rB - E}\right)B_u - B_a\right\} \qquad 9$$

The minus sign indicates that the quantity obtained by this formula is subtracted from the variety sum of squares obtained directly from the variety totals. The resulting sum of squares will yield a variety variance that can be tested directly against the intrablock error.

Repetition of Groups in Partially Balanced Lattice Experiments

A design very frequently used is the simple or triple lattice in which the groups are repeated in order to obtain the necessary number of replications. For 6 replications the groups of a simple lattice must be repeated 3 times and in a triple lattice they must be repeated twice. In order to analyze such experiments our methods must be modified slightly.

The main difference in method is in the calculation of the sum of squares for blocks from which the effect of varieties has been eliminated. For example, if we have a simple lattice in which there are 3 replicates of each group, the block totals can be set up as in the following diagram.

	Block	*Repetitions*				*Block*	*Repetitions*		
		1	2	3			1	2	3
Group A	1	—	—	—	Group B	1	—	—	—
	2	—	—	—		2	—	—	—
	3	—	—	—		3	—	—	—
	.					.			
	.					.			
	p	—	—	—		p	—	—	—

Thus block 1 of Group A is repeated 3 times and from the differences among such blocks we can obtain an estimate of the block effect directly without adjusting for the effect of varieties, which if there are n repetitions, will be represented in each group by $(n - 1)(p - 1)$ *DF*, and in an experiment with k groups by a total of $k(n - 1)(p - 1)$ *DF*. Since r (number of replicates) $= kn$, this simplifies to $(r - k)(p - 1)$ for the general case. The method of obtaining the sum of squares will be obvious to anyone familiar with the elements of the analysis of variance. It is exactly similar to the procedure for calculating the sum of squares for an interaction in a $p \times n$ fold table.

The analysis of variance for a partially balanced lattice experiment with repetitions of the groups will be of the following form. It will be noted

Form of Analysis of Variance Where Groups are Repeated

	DF		MS
Replicates	$r - 1$		
Blocks	$r(p - 1)$	$(r - k)(p - 1)$ Component **a**; $k(p - 1)$ Component **b**	B
Varieties	$p^2 - 1$		
Intrablock error	$(p - 1)(rp - p - 1)$		E
Total	$rp^2 - 1$		

that the sum of squares for blocks is divided into components **a** and **b** where **a** represents the component that is obtained directly as described above. Component **b** is determined in the same manner as in an experiment that is not repeated after the totals for similar blocks have been combined. This means that the formula for the sum of squares corresponding to 3 above is

$$\text{Component } \mathbf{b} = \frac{\Sigma(W_v^2)}{r(k - 1)p^2} \tag{10}$$

where W_v is as in formula 2 except that b_v is a total of similar blocks within a group.

In determining the value of λ we should note that the fundamental formula is

$$\lambda = (k - 1)\left\{\frac{w - w'}{(k - 1)w + w'}\right\} \tag{11}$$

where

$$w = \frac{1}{E} \qquad w' = \frac{r - 1}{rB - E} \tag{12}$$

Substituting for w and w' in 11 we get the formula for λ when the groups are repeated, in a form which is more suitable for calculation.

$$\lambda = (k - 1)\left\{\frac{r(B - E)}{r(k - 1)B + (r - k)E}\right\} \tag{13}$$

The equation for the corrections to the variety totals will be essentially the same as 5. Thus, a corrected total is given by

$$rt_v = T_v + \left\{\frac{\lambda}{(k-1)p}\right\} W_v \tag{14}$$

Finally, the variances for differences between means of varieties can be determined by using formulas 6, 7, and 8, with the exception that r is substituted for k outside the main bracket but not inside the bracket.

One characteristic of experiments with repeated groups is that if there are sufficient degrees of freedom available for the estimate of B from component **a** alone, it is unnecessary to determine component **b**. We will then have

$$w = \frac{1}{E} \qquad w' = \frac{1}{B} \tag{15}$$

where B represents component **a**. Further

$$\lambda = \frac{(k-1)(B-E)}{(k-1)\,B+E} \tag{16}$$

In general it can be taken that a simple lattice with 6 replications or a triple lattice with 9 replications is sufficiently large to justify using component **a** only in order to estimate the value of B.

In order to make the more accurate test of the variety differences we calculate the adjustment to the variety sum of squares as follows.

$$\text{Adjustment} = -\lambda\left[\left\{\frac{rB+(r-2)E}{rB-E}\right\} B_u - B_a\right] \tag{17}$$

Where B_u is the unadjusted sum of squares calculated from the totals by groups of similar blocks and B_a is component **b**.

The Balanced Lattice

The method of analysis is similar to that for the partially balanced lattice with certain simplifications. In the first place the values of y are more easily computed. For any one variety, y_v can be equated to $pT_v + G$, where G is the grand total of the experiment. Therefore W_v is given by

$$W_v = pT_v + G - rb_v \tag{18}$$

In the second place, since all comparisons are made with equal precision, there will be only one variance for differences between means of varieties, which is given by formula 6.

A third simplification arises in making the F test of the adjusted variety variance. The sum of squares for varieties adjusted for blocks is given by

$$\text{Adjusted variety (SS)} = \frac{\dfrac{\Sigma(rt_v)^2}{r} - \dfrac{G^2}{rp^2}}{1+\dfrac{\lambda}{p}} \tag{19}$$

In other words we determine the sum of squares of the corrected variety totals and divide by $1 + \lambda/p$.

Example 1. Quadruple Lattice—Partially Balanced Lattice with 4 Groups.

In this example

v (number of varieties) $= p^2 = 25$

r (number of replications) $= k$ (number of groups) $= 4$

The procedure can be carried out in steps as enumerated below.

1. Individual plot yields are taken directly from the field records and entered in Table 1. Note that the variety numbers are arranged in systematic order in accordance with the original squares of variety numbers that were written out before the test was randomized. The systematic order is not essential but is a convenience in calculation. If a preliminary test of the variety variance is to be made we would proceed directly to a determination of the variety totals as in step 3 below.

2. Determine block totals and enter in Table 1. These are indicated by b.

3. Obtain variety totals from Table 1 and enter them in the form of a square as in Table 2. Determine row and column totals of this table.

4. Enter values of y in Table 1 and calculate $y - rb$ for each block. In replicate 1 the required values of y are the row totals of Table 2, and in replicate 2 they are the column totals. For the third replicate we can obtain y from the totals of the diagonals of Table 2, beginning with the variety 11 in order to obtain the first total. If Table 2 is re-written so that the numbers in the diagonals form the rows of the new table, the totals of the diagonals of this table will give y for replicate 4. With a little practice the required totals can be obtained from Table 2 directly without re-writing. Note that for any one block the corresponding y is the sum of totals of the varieties that occur in that block. Thus we can obtain y for any block simply by summing the required variety totals and it is not necessary to follow the method outlined above.

5. Calculate W_v for each variety and enter in Table 3. For each variety W_v is the sum of the corresponding values of $y - rb$. Thus for variety 23 we have

$$W_{23} = -173.9 - 153.2 + 262.4 + 63.0 = -1.7$$

6. Calculate the sum of squares for blocks from which the effect of varieties has been eliminated, using formula 2 or 3. For formula 3 we have

$$\text{Blocks (SS)} = \frac{282{,}806.58}{300} = 942.689$$

7. If a preliminary analysis of variance has not been carried out, obtain at this point the total sum of squares and the sums of squares for replicates and varieties, using individual yields, replicate totals, and variety totals. In this example.

$$\text{Replicate (SS)} = \frac{2{,}319{,}929.88}{25} - \frac{(2990.2)^2}{300} = 3384.235$$

$$\text{Varieties (SS)} = \frac{364{,}310.820}{4} - \frac{(2990.2)^2}{300} = 1664.745$$

$$\text{Total (SS)} = 96{,}389.900 - \frac{(2990.2)^2}{300} = 6976.940$$

The sum of squares for intrablock error can be obtained by subtraction of blocks, replicates, and varieties from the total.

8. The analysis of variance can now be set up and the values of B and E calculated. In this example the analysis is as follows

	SS	DF	MS
Replicates	3384.235	3	
Blocks, eliminating varieties	942.689	16	$58.9181 = B$
Varieties, ignoring blocks	1664.745	24	
Intrablock error	985.271	56	$17.5941 = E$
Total	6976.940	99	

We note that B is considerably larger than E so we decide that the incomplete blocks have provided reasonable error control and we proceed to complete the analysis.

9. Calculate λ and set up the equation for obtaining the corrected variety totals or corrected variety means. Here, we have

$$\lambda = \frac{58.9181 - 17.5941}{58.9181} = 0.701{,}380$$

and

$$\frac{\lambda}{(r-1)p} = \frac{0.701{,}380}{15} = 0.046{,}759$$

Applying the equation for obtaining the corrected variety totals to variety 12 we have

$$rt_{12} = 132.5 + 0.046{,}759 \times 49.7 = 105.81$$

As a check on the work it is useful to take the corrected totals to at least 2 decimal places. The total of these should then check very closely with the grand total as previously determined.

10. Calculate the variances and standard errors for differences between means of varieties. The mean variance for such comparisons will in nearly all cases be sufficient but the calculation of the others is given below for reference

$$V_s = \frac{2 \times 17.5941}{4}\left(1 + \frac{0.701{,}380}{5}\right)$$

$$= 8.797{,}05 \times 1.14028 \qquad = 10.0311$$

$$V_d = 8.797{,}05\left(1 + \frac{4}{3} \times 0.140{,}28\right) = 10.4424$$

$$V_m = 8.797{,}05\left(1 + \frac{10}{9} \times 0.140{,}28\right) = 10.1683$$

The square roots of the above variances will of course give the required standard errors.

11. Finally, we can if we wish make an accurate test of the significance of the variety variance adjusted for the effect of blocks. This step is not essential in that we could make a test of the unadjusted variety variance as indicated in step 1 above, assuming that the experiment had been laid out in randomized blocks, and this test would be sufficient in most cases. The more accurate test however, is easily carried out and generally the experimenter will wish to do it in order to have his records complete.

Following formula 9 we first calculate B_u, the unadjusted sum of squares for blocks. In this example

$$B_u = \frac{470{,}421.08}{5} - \frac{2{,}319{,}929.88}{25} = 1287.021$$

Also

$$\frac{rB}{rB - E} = \frac{4 \times 58.9181}{4 \times 58.9181 - 17.5941} = 1.080{,}678$$

The adjustment to the variety sum of squares is then

$$-0.701{,}380\ \{(1.080{,}678 \times 1287.021) - 942.689\} = -314.335$$

Subtracting 314.335 from 1664.745 we have 1350.41 and the adjusted variety variance is $1350.41/24 = 56.267$, and $F = 56.267/17.5941 = 3.20$, which can be compared with a 5% point of 1.72 for 24 and 56 degrees of freedom.

Example 2. Partially Balanced Lattice (Simple) with Groups Repeated

Number of varieties $(v) = p^2 = 16$
Number of groups $(k) = 2$
Number of replications $(r) = 2k = 4$

The procedure of the analysis can be carried out in steps comparable with those of Example 1, which should be worked out before attempting Example 2.

1. The individual plot yields are taken directly from the field records and entered in Table 4. This table is comparable to Table 1 but note that replicates 1 and 3 belong to the same group and the yields by varieties and blocks are combined in the column headed group A. Similarly, the results for replicates 2 and 4 are combined in the column headed group B. After completing Table 4 we can if we wish obtain the variety totals as in 3 below and make the preliminary analysis assuming that the test has been laid out in randomized blocks.

2. Obtain all block totals and corresponding totals by groups which are represented by b. The differences between the totals of corresponding blocks should also be entered in Table 4 at this stage. These are to be used later in the calculation of component **a** for blocks.

3. Determine variety totals and enter in the form of a square as in Table 5, and obtain row and column totals.

4. Enter the values of y in Table 4. In group A these are the row totals of Table 5, and in group B they are the column totals. Note that 1558.8 in block 1 of group A is the sum of the totals for the varieties that

occur in that block. Consequently, regardless of the number of groups in the experiment y can be obtained by summing the totals for the varieties that occur in a given block. In a simple lattice y values are always given by the row and column totals of Table 5, and in a triple lattice by the totals of the rows, columns, and diagonals. After entering y we determine the required values of $y - kb$ and enter them immediately below.

5. Calculate W_v for each variety and enter in Table 6. For each variety W_v is the sum of the corresponding values of $y - kb$. Thus for variety 32 we have

$$W_{32} = 76.4 + 65.9 = 142.3$$

6. Calculate the sums of squares for blocks. It will be necessary to determine both component **a** and component **b**. If the differences between comparable blocks are represented by d and their totals for each group by D, the sum of squares for component **a** is given in this example by

$$\text{Component } \mathbf{a} = \frac{\Sigma(d^2)}{2p} - \frac{\Sigma(D^2)}{2p^2}$$

$$= \frac{15{,}899.65}{8} - \frac{28{,}040.05}{32} = 1111.204$$

Note that if there had been more than 2 replications in each group it would have been necessary to calculate componant **a** by the method described on page 12.

Component **b** can be calculated from formula 1 or 3. In formula 3 the divisor is $r(k - 1)p^2$ in place of $r(r - 1)p^2$. Using formula 3 in this example we have

$$\text{Component } \mathbf{b} = \frac{96{,}833.58}{64} = 1513.025$$

Combining components **a** and **b** we have 2624.23 as the sum of squares for blocks from which the effect of varieties has been eliminated.

7. If a preliminary analysis has not been carried out, calculate at this stage the total sum of squares and the sums of squares for replicates and varieties, and obtain the sum of squares for intrablock error by subtraction from the total.

8. Set up the analysis of variance as follows and determine the values of B and E.

	SS	DF	MS
Replicates	882.95	3	
Blocks, eliminating varieties	2624.23	12	218.686 = B
Varieties, ignoring blocks	7389.88	15	
Intrablock error	3584.61	33	108.624 = E
Total	14,481.67	63	

Since B is about twice as large as E we can assume that the lattice design has contributed to the accuracy of the experiment and we proceed to the completion of the analysis.

9. Calculate λ from formula 13 and set up the equation for obtaining the corrected variety totals as in formula 14. In this example

$$\lambda = \frac{2(218.686 - 108.624)}{2 \times 218.686 + 108.624} = 0.403{,}160$$

and

$$\frac{\lambda}{(k-1)p} = \frac{0.403{,}160}{4} = 0.100{,}790$$

To obtain the corrected total for variety 42

$$rt_{42} = 289.6 + 0.100{,}790 \times 77.8 = 297.44$$

10. The variances of differences between means of varieties are

$$V_s = \frac{2 \times 108.624}{4}\left(1 + \frac{0.403{,}160}{4}\right)$$

$$= 54.3120 \times 1.100{,}790 \qquad = 59.7861$$

$$V_d = 54.3120\left\{1 + \left(\frac{2}{1}\right) \times 0.100{,}790\right\} = 65.2602$$

$$V_m = 54.3120\left\{1 + \left(\frac{8}{5}\right) \times 0.100{,}790\right\} = 63.0704$$

and the square roots of these give the required standard errors.

11. In order to make an accurate test of the significance of the variety variance after adjustment for the effect of the blocks we calculate B_u, which is the unadjusted sum of squares for component **b**, as follows.

$$\frac{(820.2)^2 + (728.9)^2 = \ldots . + (790.4)^2}{8} - \frac{(2985.0)^2 + (3005.7)^2}{32}$$

$$= 2893.055$$

Also

$$\frac{rB + (r-2)E}{rB - E} = \frac{4 \times 218.686 + 2 \times 108.624}{4 \times 218.686 - 108.624} = -\ 1.425{,}36$$

Then the adjustment is

$$-\ 0.403{,}160\ \{(1.425{,}36 \times 2893.055) - 1513.025\} = 1052.498$$

and the adjusted variety sum of squares is 7389.88 − 1052.50 = 6337.38. The adjusted variety variance is 6337.38/15 = 422.49 and F is 422.49/108.62 = 3.89.

Example 3. Balanced Lattice. In this example

number of varieties $(v) = p^2 = 25$

number of replicates $(r) = p + 1 =$ number of groups $(k) = 6$.

The procedure is identical with that for partially balanced lattices without repetition of groups, except for a few simplifications. Enumerating the steps we have

1. Individual plot yields are taken directly from the field record and entered in Table 7. The block and replicate totals are determined and entered in the same table.

2. Determine the variety totals from Table 7 and enter opposite the variety numbers in Table 8. If we wish to make a preliminary analysis of variance assuming the test laid out in randomized blocks, it would be carried out at this stage.

3. Calculate W_v for each variety using formula 18. Thus for variety 24 we would have

$$W_{24} = 5 \times 257.3 + 6245.2 - 6(205.7 + 212.4 + \ldots 189.1) = -24.1$$

4. Calculate the sum of squares for blocks from which variety effects have been eliminated using formula 3.

$$\text{Blocks (SS)} = \frac{921{,}964.14}{750} = 1229.29$$

5. The remaining sums of squares are determined and the analysis of variance set up from which B and E are calculated.

	SS	DF	MS
Replicates	416.51	5	
Blocks, eliminating varieties	1229.29	24	51.220 = B
Varieties, ignoring blocks	2431.48	24	
Intrablock error	1601.46	96	16.682 = E
Total	5678.74	149	

6. Compute the value of λ using formula 4, and set up equation 5 for obtaining the corrected variety totals.

$$\lambda = \frac{51.220 - 16.682}{51.220} = 0.674{,}307$$

and

$$\frac{\lambda}{(r-1)P} = \frac{0.674{,}307}{25} = 0.026{,}972{,}3$$

Then $rt_{24} = 257.3 - 0.026{,}972{,}3 \times 24.1 = 256.65$. These are entered in Table 8 and from them we determine the corrected variety means.

7. The variance of a difference between two variety means is

$$V_s \doteq \frac{2 \times 16.682}{6}\left(1 + \frac{0.674{,}307}{5}\right) = 6.3108$$

8. In order to make an accurate test of the variety variance we require the sum of squares of the corrected variety totals. This is divided by $1 + \lambda/p$, giving the adjusted sum of squares for varieties directly.

$$\text{Corrected variety totals (SS)} = \frac{1{,}573{,}757.703}{6} - \frac{(6245.2)^2}{150} = 2276.13$$

This is divided by $1 + \lambda/p$ which has been determined above to be 1.134,86. We have, 2276.13/1.134,86 = 2005.65, and the mean square is 2005.65/24 = 83.568. Then $F = 83.568/16.682 = 5.01$.

TABLE 1—INDIVIDUAL PLOT YIELDS, BLOCK TOTALS, AND VALUES OF y AND $y - rb$ QUADRUPLE LATTICE WITH 25 VARIETIES IN 4 REPLICATIONS

Block no.	Repl. 1		Repl. 2		Repl. 3		Repl. 4	
	Var. no.	Group A	Var. no.	Group B	Var. no	Group C	Var. no.	Group D
1	11 12 13 14 15	27.4 38.6 29.1 21.3 34.1	11 21 31 41 51	37.2 37.5 18.0 42.2 43.3	11 22 33 44 55	23.4 19.0 11.8 13.3 18.9	11 32 53 24 45	20.0 20.8 27.6 23.9 25.5
b y $y - rb$		150.5 575.5 −26.5		178.2 578.8 −134.0		86.4 584.4 238.8		117.8 576.8 105.6
2	21 22 23 24 25	36.6 46.1 44.7 40.6 37.3	12 22 32 42 52	40.9 44.2 36.7 34.8 35.8	21 32 43 54 15	22.5 22.7 25.0 22.3 34.0	21 42 13 34 55	23.8 38.5 25.4 30.1 29.8
b y $y - rb$		205.3 647.3 −179.3		192.4 616.3 −153.3		126.5 628.5 122.5		147.6 597.6 7.2
3	31 32 33 34 35	16.7 30.0 28.0 33.3 26.2	13 23 33 43 53	31.6 45.0 37.8 40.8 36.4	31 42 53 14 25	18.0 19.3 25.0 19.9 28.3	31 52 23 44 15	21.0 21.5 34.5 21.0 32.5
b y $y - rb$		134.2 516.6 −20.2		191.6 613.2 −153.2		110.5 536.4 94.4		130.5 585.0 63.0
4	41 42 43 44 45	40.1 25.6 39.7 36.4 37.3	14 24 34 44 54	24.4 28.0 38.6 38.8 36.0	41 52 13 24 35	22.7 25.0 22.4 25.4 24.4	41 12 33 54 25	39.2 39.9 28.4 28.2 32.7
b y $y - rb$		179.1 622.5 −93.9		165.8 562.0 −101.2		119.9 594.5 114.9		168.4 640.7 −32.9
5	51 52 53 54 55	33.4 38.8 35.0 37.6 38.4	15 25 35 45 55	39.3 35.6 31.2 37.3 39.5	51 12 23 34 45	27.8 13.1 16.6 21.9 16.6	51 22 43 14 35	28.0 25.0 28.4 21.0 21.0
b y $y - rb$		183.2 628.3 −104.5		182.9 619.9 −111.7		96.0 646.4 262.4		123.4 590.1 96.5
Replicate totals		852.3		910.9		539.3		687.7

NOTE—Check calculations from $\Sigma(y - rb)$ over all blocks = 0.

TABLE 2.—VARIETY TOTALS (T_v) — *Quadruple Lattice*

Variety numbers	11	12	13	14	15	Row totals
Variety totals	108.0	132.5	108.5	86.6	139.9	575.5
Variety numbers	21	22	23	24	25	
Variety totals	120.4	134.3	140.8	117.9	133.9	647.3
Variety numbers	31	32	33	34	35	
Variety totals	73.7	110.2	106.0	123.9	102.8	516.6
Variety numbers	41	42	43	44	45	
Variety totals	144.2	118.2	133.9	109.5	116.7	622.5
Variety numbers	51	52	53	54	55	
Variety totals	132.5	121.1	124.0	124.1	126.6	628.3
Column totals	578.8	616.3	613.2	562.0	619.9	2990.2 = G

TABLE 3.—VALUES BY VARIETIES OF W_v, rt_v, AND t_v—QUADRUPLE LATTICE

Variety numbers	W_v	rt_v	t_v
11	183.9	116.60	29.2
12	49.7	134.82	33.7
13	−57.6	105.81	26.4
14	63.2	89.56	22.4
15	47.3	142.11	35.5
21	−178.2	112.07	28.0
22	8.1	134.68	33.7
23	−1.7	140.72	35.2
24	−54.6	115.35	28.8
25	−224.1	123.42	30.8
31	3.2	73.85	18.5
32	54.6	112.75	28.2
33	32.5	107.52	26.9
34	148.2	130.83	32.7
35	79.5	106.52	26.6
41	−145.9	137.38	34.3
42	−145.6	111.39	27.8
43	−28.1	132.59	33.1
44	106.7	114.49	28.6
45	162.4	124.29	31.1
51	120.4	138.13	34.5
52	−79.9	117.36	29.3
53	−57.7	121.30	30.3
54	−116.1	118.67	29.7
55	29.8	127.99	32.0
Sum =	0	2990.2	

TABLE 4.—INDIVIDUAL PLOT YIELDS, BLOCK TOTALS, GROUP TOTALS AND VALUES OF y_v AND $y_v - rb_v$. SIMPLE LATTICE WITH 16 VARIETIES IN 4 REPLICATIONS

Block no.	Var. no.	Repl. 1	Repl. 3	Group A	Var. no.	Repl. 2	Repl. 4	Group B
1	11	93.6	105.0	198.6	11	76.0	85.0	161.0
	12	99.5	97.0	196.5	21	113.5	115.6	229.1
	13	113.3	115.2	228.5	31	84.4	101.5	185.9
	14	100.8	95.8	196.6	41	87.5	98.6	186.1
Totals		407.2	413.0	820.2 (b)		361.4	400.7	762.1 (b)
		−5.8 (d)		1558.8 (y)		−39.3 (d)		1529.2 (y)
				−81.6 ($y - kb$)				5.0 ($y - kb$)
2	21	109.0	102.7	211.7	12	98.1	78.2	176.3
	22	90.6	95.3	185.9	22	78.2	83.1	161.3
	23	79.4	106.6	186.0	32	93.0	93.6	186.6
	24	73.0	72.3	145.3	42	48.8	73.7	122.5
Totals		352.0	376.9	728.9 (b)		318.1	328.6	646.7 (b)
		−24.9 (d)		1471.8 (y)		−10.5 (d)		1359.3 (y)
				14.0 ($y - kb$)				65.9 ($y - kb$)
3	31	76.1	105.0	181.1	13	113.1	102.5	215.6
	32	61.6	101.5	163.1	23	75.9	91.7	167.6
	33	80.6	93.0	173.6	33	104.5	78.2	182.7
	34	88.5	103.3	191.8	43	129.7	110.9	240.6
Totals		306.8	402.8	709.6 (b)		423.2	383.3	806.5 (b)
		−96.0 (d)		1495.6 (y)		39.9 (d)		1606.1 (y)
				76.4 ($y - kb$)				−6.9 ($y - kb$)
4	41	89.6	86.1	175.7	14	71.6	114.1	185.7
	42	76.4	90.7	167.1	24	92.5	92.4	184.9
	43	100.6	110.9	211.5	34	117.8	113.0	230.8
	44	80.2	91.8	172.0	44	92.6	96.4	189.0
Totals		346.8	379.5	726.3 (b)		374.5	415.9	790.4 (b)
		−32.7 (d)		1464.5 (y)		−41.4 (d)		1496.1 (y)
				11.9 ($y - kb$)				−87.7 ($y - kb$)
Replicate Totals and Group Totals		1412.8	1572.2	2985.0		1477.2	1528.5	3005.7
		−159.4 (D)		5990.7 (Σy) $= G$		−51.3 (D)		5990.7 (Σy) $= G$
				20.7 (S)				−20.7 (S)

TABLE 5.—VARIETY TOTALS (T_v). SIMPLE LATTICE WITH 16 VARIETIES IN 4 REPLICATIONS

					Row totals
Variety numbers	11	12	13	14	
Variety totals	359.6	372.8	444.1	382.3	1558.8
Variety numbers	21	22	23	24	
Variety totals	440.8	347.2	353.6	330.2	1471.8
Variety numbers	31	32	33	34	
Variety totals	367.0	349.7	356.3	422.6	1495.5
Variety numbers	41	42	43	44	
Variety totals	361.8	289.6	452.1	361.0	1464.5
Column totals	1529.2	1359.3	1606.1	1496.1	5990.7

TABLE 6—VALUES BY VARIETIES OF W_v, rt_v, AND t_v. SIMPLE LATTICE WITH 16 VARIETIES IN 4 REPLICATIONS

Variety Numbers	W_v	rt_v	t_v
11	−76.6	351.88	88.0
12	−15.7	371.22	92.8
13	−88.5	435.18	108.8
14	−166.3	365.54	91.4
21	19.0	442.72	110.7
22	79.9	355.25	88.8
23	7.1	354.32	88.6
24	−70.7	323.07	80.8
31	81.4	375.20	93.8
32	142.3	364.04	91.0
33	69.5	363.30	90.8
34	−8.3	421.76	105.4
41	16.9	363.50	90.9
42	77.8	297.44	74.4
43	5.0	452.60	113.2
44	−72.8	353.66	88.4
Totals	0	5990.7	

TABLE 7.—INDIVIDUAL PLOT YIELDS AND BLOCK AND REPLICATE TOTALS. BALANCED LATTICE WITH 25 VARIETIES

	Replicate 1		Replicate 2		Replicate 3		Replicate 4		Replicate 5		Replicate 6	
	11	34.5	11	39.1	11	42.3	11	42.2	11	37.2	11	40.0
	12	48.6	21	41.5	22	41.1	32	44.8	42	33.9	52	46.3
	13	45.9	31	35.9	33	36.0	53	34.7	23	32.0	43	40.2
	14	45.1	41	44.6	44	44.2	24	43.7	54	42.7	34	46.7
	15	44.6	51	43.2	55	44.1	45	40.0	35	40.6	25	36.6
b_v		218.7		204.3		207.7		205.4		186.4		209.1
	21	51.1	12	43.2	21	34.6	21	43.7	21	50.8	21	48.8
	22	46.9	22	46.5	32	44.3	42	23.9	52	47.4	12	46.2
	23	31.0	32	49.6	43	44.7	13	39.1	33	37.0	53	44.3
	24	42.4	42	45.1	54	38.3	34	38.5	14	46.7	44	47.3
	25	34.3	52	48.8	15	36.7	55	38.5	45	47.2	35	49.2
b_v		205.7		233.2		198.6		183.7		229.1		235.8
	31	32.7	13	49.8	31	30.9	31	34.9	31	26.5	31	31.4
	32	36.6	23	33.4	42	46.1	52	42.0	12	45.8	22	40.8
	33	43.3	33	41.4	53	42.6	23	30.6	43	39.5	13	40.8
	34	49.2	43	44.0	14	46.6	44	41.5	24	40.2	54	35.3
	35	35.1	53	41.5	25	31.0	15	44.6	55	42.3	45	32.3
b_v		196.9		210.1		197.2		193.6		194.3		180.6

Table 7.—Individual plot yields and block and replicate totals. Balanced lattice with 25 varieties—*Concluded*

Replicate 1		Replicate 2		Replicate 3		Replicate 4		Replicate 5		Replicate 6	
41	50.5	14	46.6	41	50.1	41	50.9	41	23.6	41	41.4
42	40.2	24	40.8	52	46.4	12	46.7	22	53.2	32	39.3
43	46.9	34	40.0	13	52.8	33	41.4	53	38.2	23	29.8
44	48.3	44	37.6	24	51.4	54	43.1	34	44.6	14	36.0
45	55.0	54	47.4	35	51.7	25	35.6	15	43.1	55	35.8
b_v	240.9		212.4		252.4		217.7		202.7		182.3
51	44.6	15	44.8	51	46.9	51	40.1	51	31.6	51	42.4
52	48.8	25	37.0	12	50.8	22	48.8	32	35.5	42	38.2
53	48.8	35	44.6	23	34.4	43	40.0	13	39.5	33	34.9
54	41.2	45	34.4	34	46.8	14	48.3	44	35.7	24	38.8
55	41.1	55	44.0	45	46.3	35	44.2	25	29.1	15	34.8
b_v	224.5		214.8		225.2		221.4		171.4		189.1
Replicate Totals	1086.7		1074.8		1081.1		1021.8		983.9		996.9

Table 8.—Values by varieties of T_v, W_v, rt_v, and t_v. Balanced lattice with 25 varieties

Variety numbers	T_v	W_v	rt_v	t_v
11	235.3	32.1	236.16	39.4
12	281.3	−297.7	273.27	45.5
13	267.9	283.3	275.54	45.9
14	269.3	25.1	269.98	45.0
15	248.6	183.2	253.54	42.2
21	270.5	54.5	271.97	45.3
22	277.3	123.9	280.64	46.8
23	191.2	−18.6	190.70	31.8
24	257.3	−24.1	256.65	42.8
25	203.6	−32.2	202.73	33.8
31	192.3	205.3	197.84	33.0
32	250.1	368.9	260.05	43.6
33	234.0	−88.4	231.62	38.6
34	265.1	190.7	270.24	45.0
35	265.4	−274.0	258.01	43.0
41	261.1	−251.1	254.33	42.4
42	227.4	−0.8	227.38	37.9
43	255.3	−124.7	251.94	42.0
44	254.6	−52.6	253.18	42.2
45	265.2	−204.8	259.68	43.3
51	248.8	73.8	250.79	41.8
52	279.7	−407.7	268.70	44.8
53	250.1	−158.5	245.82	41.0
54	248.0	164.0	252.42	42.1
55	245.8	230.4	252.01	42.0
Totals	6245.2	0	6245.2	

TABLE 9.—AVAILABLE AND RECOMMENDED SQUARE LATTICE DESIGNS FOR DIFFERENT NUMBERS OF VARIETIES

Number of varieties	Number of replications										
	2	3	4	5	6	7	8	9	10	11	12
9	S	T	B* SR		SR TR*		SR BR*	TR	SR		SR TR*
											BR*
16	S	T	Q* SR	B	SR TR*		SR QR*	TR	SR BR*		SR TR QR*
25	S	T	Q* SR	P5	B* SR		SR QR*	TR	P5R* SR		SR TR QR BR*
36	S	T	SR		SR TR*		SR	TR	SR		SR TR*
49	S	T	Q* SR	P5	P6* SR TR	P7	B* SR QR	TR	SR P5R*		SR TR QR*
64	S	T	Q* SR	P5	P6* SR TR	P7	P8 SR QR*	B* TR	SR P5R*		SR TR QR P6R*
81	S	T	Q* SR	P5	P6* SR TR	P7	P8 SR QR*	P9 TR*	B* SR P5R		SR TR QR P6R*
100	S	T	SR		TR		SR	TR	SR		SR TR*
121	S	T	Q* SR	P5	P6* SR TR	P7	P8 SR QR*	P9 TR*	P10 SR P5R*	P11	B* SR TR P6R
144	S	T	Q SR		SR TR		SR QR	TR	SR		SR TR QR
169	S	T	Q* SR	P5	P6* SR TR	P7	P8 SR QR*	P9 TR*	P10 SR P5R*	P11	P11 SR TR QR* P6R

KEY TO SYMBOLS—

S Simple Lattice
T Triple Lattice
Q Quadruple Lattice
P5 Quintuple Lattice
P6, etc. Lattice of higher order than Quintuple
SR Simple Lattice Repeated
TR Triple Lattice Repeated
QR Quadruple Lattice Repeated
P5R etc. Quintuple Lattice Repeated, etc.

* Where more than one type is possible the type recommended is marked with an asterisk.

RECOMMENDED TYPES OF SQUARE LATTICE DESIGNS

Table 9 gives the possible types of square lattice designs for numbers of varieties from 9 to 169 and numbers of replicates from 2 to 12. When more than one type can be used with a given number of replicates, the one recommenced is marked with an asterisk. This table can be used as follows. An experimenter wishes to test 49 varieties and decides that 6 is the maximum number of replicates that can be carried. The table gives 3 types of designs that are possible and the one marked with an asterisk is P6. This means a type in which there are 6 orthogonal groups, a different group for each replicate. It should be borne in mind in selecting these types that the differences between them are often inconsequential. Thus with 49 varieties the triple lattice repeated would be preferred by some because there would be a little less work involved in the analysis. It has been assumed in making up Table 9 that it is feasible to use partially balanced square lattice experiments up to 6 replications without repetition. Beyond that it is deemed advisable to repeat a lattice of a simpler type in order to obtain the required number of replications.

SUMMARY

1. The fundamental characteristics of square lattice designs are discussed and a generalized method of analysis presented for all such designs.

2. A table is presented showing the possible types of square lattice designs within a useful range of numbers of varieties and replicates and certain recommendations are made.

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ACIDITY: ITS RELATION TO BUTTER FLAVOUR[1]

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In Canada, where a greater proportion of the creamery butter is manufactured during the spring and summer months and the surplus stored for periods of 3 to 9 months, it is important that the original quality of the cream and subsequent manufacturing procedures be such that the flavour quality of the butter does not undergo undue deterioration. Research work over the years has indicated that the churning acidity of the cream, and therefore the acidity of the butter serum, is one of the most important factors affecting both the initial and keeping quality of butter flavour.

The earlier investigations (10, 12, 13, 14, 16) were concerned mainly with the cream acidity at churning and the keeping quality of the butter, and the results showed that butter from sweet cream or cream of low acidity had much better keeping quality than butter from high acid cream. More recently Holm *et al.* (3) have shown that the rate of deterioration of flavour score for butter made from creams of 0.31 and 0.4% acidity was much more rapid than for butters made from creams churned at average acidities of 0.13 and 0.19%. They were able to correlate the loss of flavour score with increased oxidation of the fats in the high-acid butters, and concluded that the oxidation reaction seemed to underlie the various changes that resulted in a loss in score. Their data also indicated the relation between high acidity in the butter and the development of metallic and fishy flavours. Overman, Garrett and Ruehe (11) found that butters which had the highest initial scores and maintained flavour quality best during storage were made from fresh sweet creams with acidities of about 0.12%.

Studies (1, 2, 6, 7, 8) on the relation of the pH of the butter serum to keeping quality have also indicated the importance of acidity to butter flavours, and most investigators have recommended a pH of 6.7 to 7.2 in the butter serum for butters intended for storage. Bird (1) found that there was fairly close relation between the pH of butter serum and some of the common flavour defects of storage butter. At pH values below 6.6, metallic flavours became important, while fishy flavours commonly developed at pH values of 6.0 or lower. Hussong, Quam and Hammer (4) also have observed that fishy flavours are common at pH values of 6.0 or lower, or when these flavours developed at higher pH values, the butters usually contained relatively high copper contents. In studies of commercial Canadian butters (15) it was found that fishy flavours were usually present when the pH of the butter serum was about 6.0 or lower.

Investigations (5) on butter acidity at the Iowa Agricultural Experiment Station have indicated that even for creams with less than 0.2% acid, the flavour of the butter was improved by reducing the acidity to about 0.11% at churning.

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In commercial butters made from farm separated cream of varying quality, it is often difficult to attribute deterioration of flavour to any one particular factor. The present study was planned to obtain data on the effect of acidity of cream at churning on the initial and keeping quality of butter made from freshly separated sweet cream of fine flavour and from first grade farm separated cream, when other factors were the same or were carefully controlled. Data were also obtained on the relation between the titratable acidity of the cream and the pH of the butter serum, and gave some indication as to the acidity at which cream should be churned to give the best flavour.

MATERIALS AND METHODS

Fresh sweet cream from milk of the Central Experimental Farm herd was used for all churnings except for those in series 9 and 10 which were from farm separated cream obtained from a local dairy. In the present study it was aimed to have the different lots of cream in each series churned at acidities of 0.1 to 0.15, 0.2 and 0.3%. The individual churnings in each series were denoted by the letters A, B and C after the series number to indicate the churning acidity of the cream.

In series 1 and 2, a lot of about 250 pounds of cream was inoculated with 70 to 100 ml. of starter and held overnight at about 70° F. in a small stainless steel vat to develop acid. The following day the cream was neutralized to a calculated acidity of 0.3%, then pasteurized, and when cooled to about 100° to 110° F. was divided in 3 equal lots. One lot in each series was further neutralized to a calculated acidity of 0.2% and the other lot to a calculated acidity of 0.15%.

Churnings 3A, 4A and 8 were churned from freshly separated pasteurized creams of acidities of about 0.11%.

For churnings 3B, 3C, 4B, 4C, 5, 6 and 7, about 1 quart of starter was added to approximately 80 pounds of cream to develop an acidity of 0.2 or 0.3% and then pasteurized immediately the desired acidity was reached. In churnings 4C and 7, a higher acidity than was desired had developed and it was necessary to neutralize the cream.

For series 9 and 10 (churnings 9A, 9B, 9C and 10A, 10B, 10C), the farm separated cream was thoroughly mixed, divided into 3 equal lots and each lot neutralized to the desired acidity before pasteurization.

All creams were pasteurized at 170° to 172° F. for 10 minutes, cooled to 40° F. and held overnight before churning. A sodium sesquicarbonate neutralizer was used to reduce the acidity when necessary. Churnings were salted at a rate of 1.5% on the estimated butter. The butters were packed in 14-lb. spruce boxes lined with double 40-lb. parchments and placed in storage immediately at temperatures of about 12° F. and −10° F. The butters were scored within 2 weeks of manufacture and again after storage periods ranging from 127 to 203 days.

Titratable acidities and pH values were determined on the creams when fresh and at the churn, and pH values of the butter sera were made before and after storage. All pH determinations were made with a Beckman pH meter with glass electrode. Peroxide values of butter were made on the surface and interior portions of the butters using a modified iodi-

metric method in an attempt to evaluate the extent of deterioration of an oxidative nature. Copper contents were determined by the filtration method of Moir and Andrews (9).

Microbiological analyses were run on the butters when fresh using tryptone glucose extract agar for the standard plate count plus 0.5 ml. sterile skimmilk and 0.5 ml. of a sterile fat-agar emulsion in each Petri dish, to obtain an estimate of the numbers of proteolytic and lipolytic colonies present. Malt extract agar acidified to a pH of 3.5 ± was used for mould and yeast counts.

RESULTS

Data on the titratable acidities and pH values of the creams and the pH values of the butters before and after storage are given in Table 1 and indicate the treatment of the creams before churning.

With the exception of a few churnings in the low acid group, the data show a close agreement between the pH of the cream at the churn and the pH of the butter serum both when fresh and after storage. There was also good agreement between the pH values of the butters when fresh and after storage and for the same butters stored at different temperatures. With the equipment used, the pH values of the cream were slightly higher than for the resulting butters in the majority of churnings. In the case of the butters, the pH values after storage were slightly higher than when fresh, but in many instances the differences were negligible. With the exception of the first three churnings in the low acid group and one churning in the medium acid group, the variation in pH values between fresh and storage butters did not exceed 0.2 of one full division on the pH scale.

Creams with acidities of 0.10 to 0.15% gave pH values in the butter serum ranging from 6.43 to 6.95 after storage at 12° F. with an average value of 6.76; creams with acidities of 0.17 to 0.23 gave butters with pH values of 5.94 to 6.28 with an average pH of 6.11; while the butters from creams of 0.29 to 0.35% acid had pH values of 5.35 to 5.73 with an average pH value of 5.51.

The relation between acidity and flavour score for individual churnings is shown by the data presented in Table 2. With the exception of churning 1A, where the cream developed an off flavour which carried through the whole series of 3 churnings, all fresh butters with acidities below 0.15% had flavour scores of 39.5 to 40.5. Creams in the medium acid group gave butters which had flavour scores of 39.0, or 39.5 in the case of two churnings, with the exception of 1B. In several cases, however, the graders' remarks indicated the flavour was slightly acid or showing an indication of the metallic defect. For the high acid creams ranging from 0.29 to 0.35%, 4 of the 7 butters were second grade in flavour score when fresh and 3 were scored 39.0 points. In every instance, however, the butters were criticized for metallic or acid flavours or for showing an indication of the metallic flavour.

For the majority of the butters, there was no marked deterioration in the flavour scores after storage for 4 to $6\frac{1}{2}$ months at the two temperatures used. In a few instances the flavour scores of the butter after storage were slightly higher than when graded fresh and the average score for the 7 churnings of the high acid group was slightly higher than when fresh. There was no loss of grade after storage for butters in the low acid group, but 2 churnings in the medium acid group and 1 in the high acid group lost a grade after storage.

The variation in the acidity of the same or comparable fresh sweet creams ripened by means of a lactic culture made a difference of 0.5 to 1 point between the flavour scores of individual churnings in the low acid and medium acid groups, and as much as 2 to 3 full points between the flavour scores of butters in the low and high acid groups. Similar results were obtained for butters made from mixed lots of farm separated creams (series 9 and 10) which had developed acid naturally. In other words the variation in acidity of the same cream meant a difference between a 40-score first grade butter and a second grade product in a number of comparisons.

While the surface butter was slightly lower in flavour score than the interior, there were only one or two instances in which the surface flavour of first grade butter had deteriorated sufficiently to lower the grade of the butter, and these were in the high acid groups. Only in the case of churning 10C did the graders observe a tendency towards a fishy flavour.

A summary of the data in Table 2 is given in Table 3. When fresh, the average flavour score for the low acid butters was 0.64 point higher than for the medium acid group and 1.5 points higher than for the high acid butters, while the medium acid group had an average flavour score 0.86 point higher than the high acid group. The average scores of the butters in the different groups showed approximately the same differences after storage for both the interior and surface portions.

The copper contents and the peroxide values of the butters are given in Table 4. The copper contents were quite low for all butters exept 10C and well below 0.15 p.p.m., usually considered the maximum amount for good keeping quality. There was no apparent reason for the variation in the copper content of butters 10C and 10A made from the same cream.

Peroxide values were relatively low for all butters and are in line with the values reported by Holm *et al.* (3) for butters of comparable acidities and storage temperatures. It is of interest to note, however, that as the acidity of the butters increased, the average peroxide values increased slightly. The average peroxide values of the surface of the butters were also slightly higher than for the interior which coincides with the slightly lower average flavour scores of the surface of butters in the different acid groups.

There was very little difference in the scores of individual churnings or the average scores of butter in the three acid groups when held at 12° F.

or $-10°$ F. The slight differences noted were in favour of the lower temperature and this was especially true for the churnings (series 9 and 10) made from farm separated cream. It should be mentioned, however, that much of the butter was made from cream that was of excellent quality except for the acid developed by good flavoured cultures of lactic acid bacteria.

The results of the microbiological analyses of the butters are not given in detail, as an examination of the data showed that the bacterial and total mould and yeast counts were approximately the same for butters of different acidities in the same series, and therefore would not influence the flavour scores of the butter. The standard plate counts of bacteria colonies were relatively low and ranged from 2,300 to 30,000 per ml. of butter, with all but 4 churnings having total bacteria counts of less than 15,000 per ml. Counts of proteolytic and lipolytic colonies ranged from 0 to 5,000 and 0 to 1,300, respectively, while total mould and yeast counts varied from 2 to 113 per ml.

DISCUSSION

The results obtained on these experimental butters, though limited in number, show the importance of proper control of the acidity of the cream and the pH of the butter, in order to obtain the best possible flavour scores on the finished butter. While only one churning in the high acid group showed a tendency towards a fishy flavour at the surface, the data indicated a rather definite relationship between acidity and the metallic and fishy flavour of butter. These results are in agreement with the general findings of other workers.

The flavour defect in the medium and high acid butters which was described as of a metallic nature was apparently not due to contamination with heavy metals as indicated by the copper content of butters of different acidities made from the same lot of cream, but was due to the acidity in the cream and in the resulting butter.

Under the conditions of these trials, the data indicated that the acidity of neutralized sour cream should be controlled within a range of 0.10 to 0.15 to obtain a pH in the butter serum of 6.7 to 7.2, which is generally considered advisable for salted butter intended for storage. Butters made from unneutralized sweet cream, however, may have a pH value somewhat lower than for neutralized sour cream of comparable titratable acidity without having a detrimental effect on flavour as indicated by the pH values and scores of churnings 4A and 8.

Although the values of the peroxide test, used as an indication of the oxidative changes in the fat, were relatively low for these experimental butters, the small increase in the average peroxide values as the acidity of the butters increased, suggests that acidity functions as a causative agent in oxidative changes that take place in the butterfat during storage, and which lead to flavour defects generally described as stale, storage, tallowy, metallic and fishy.

SUMMARY

The acidity of the cream, and therefore the pH of the butter serum, was found to have a definite effect on the flavour scores of the butter. As the average acidity of the cream inc reased from 0.11 to 0.20 or 0.31%, the average pH values of the butter serum decreased from 6.76 to 6.1 and 5.51, respectively, with a resulting loss in flavour scores of the butter of as much as 2 to 3 points between the low acid and high acid butters.

In the medium and high acid butters, the principle flavour defects noted were of a metallic, sour or acid, and, in one case, of a fishy nature.

The data indicated that the acidity of neutralized sour cream should be adjusted to 0.15% or lower to give a pH in the butter serum of 6.7 to 7.2 if the highest flavour scores are to be obtained on the butter when fresh and after storage.

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TABLE 1.—TITRATABLE ACIDITIES AND PH VALUES OF CREAM AND BUTTER

Churning number	Titratable acid of cream			pH of cream	pH of butter*		
	Sweet	Before neut.	At churn.	At churn.	Fresh	Held at 12° F.	Held at −10° F.
1A	0.12	0.54	0.15	6.74	6.43	6.71	6.71
2A	0.11	0.54	0.15	6.76	6.64	6.95	7.02
3A	0.11	—	0.10	7.00	6.60	6.94	6.93
4A	0.11	—	0.11	6.70	6.70	6.65	6.58
8	0.11	—	0.11	6.78	6.54	6.43	6.43
9A	—	0.32	0.09	7.05	6.88	6.82	6.92
10A	—	0.44	0.10	6.87	6.78	6.86	6.97
Ave.	0.112	—	0.116	6.84	6.65	6.76	6.78
1B	0.12	0.54	0.21	6.05	5.90	6.01	6.07
2B	0.11	0.54	0.20	6.03	5.92	6.09	6.12
3B	0.11	—	0.22	5.73	5.82	5.94	5.93
3C	0.11	—	0.17	6.28	6.15	6.28	6.41
4B	0.11	—	0.21	6.37	6.05	6.28	6.20
4C	0.11	0.54	0.23	6.29	6.00	6.10	6.12
9B	—	0.32	0.19	6.30	6.12	6.14	6.17
10B	—	0.44	0.20	6.23	6.03	6.01	6.11
Ave.	0.112	—	0.203	6.16	6.00	6.11	6.14
1C	0.12	0.54	0.30	5.57	5.34	5.54	5.57
2C	0.11	0.54	0.30	5.50	5.52	5.56	5.57
5	0.11	—	0.30	5.60	5.72	5.73	5.75
6	0.11	—	0.35	5.30	5.30	5.35	5.38
7	0.11	0.34	0.29	5.72	5.48	5.35	5.32
9C	—	0.32	0.30	5.56	5.52	5.52	5.53
10C	—	0.44	0.32	5.50	5.39	5.50	5.50
Ave.	0.112	—	0.31	5.55	5.47	5.51	5.52

* pH determinations after storage were made on a different pH meter than when fresh.

TABLE 2.—THE RELATION BETWEEN CREAM ACIDITY AND PH OF BUTTER TO FLAVOUR SCORES OF BUTTER

Churn no.	Acidity of cream at churn	pH* of butter	Fresh		After storage							
					Interior				Surface			
					at 12° F.		at −10° F.		at 12° F.		at −10° F.	
			Score	Remarks	Score	Remarks	Score	Remarks	Score	Remarks	Score	Remarks
1A	0.15	6.71	38.0	Unclean	38.5	Sl. unclean	38.0	Stale	38.5	Sl. Stale	38.0	Stale, old cream
2A	0.15	6.95	40.0	—	40.0−	—	40.0−	—	39.0+	Very sl. woody	40.0−	—
3A	0.10	6.94	39.5	—	40.0+	—	40.0+	—	40.0	—	40.0	—
4A	0.11	6.65	39.5	—	40.0	—	40.0	—	39.0	V. sl. unclean	39.0	Sl. stale
8	0.11	6.43	40.5	—	40.0−	—	39.5	—	39.5	V. sl. storage	39.0	Trace storage
9A	0.09	6.82	40.0	—	39.0	Very sl. age	40.0	—	39.0	Sl. age	40.0	—
10A	0.10	6.86	40.0	—	39.0	—	39.5	—	38.5	Sl. woody	39.0	—
Ave.	0.116	6.76	39.64		39.46		39.57		39.10		39.25	
1B	0.21	6.01	38.0	Unclean	38.5	Sl. unclean	39.0−	Sl. stale	38.0+	Sl. tallowy	38.0+	Sl. tallowy
2B	0.20	6.09	39.0	Indic. of met.	39.5	—	39.5	—	39.0	Trace storage	39.0	Sl. stale
3B	0.22	5.94	39.0	Not full flavour	39.0+	—	39.0	—	39.0	Sl. stale	39.0−	Sl. storage
3C	0.17	6.28	39.5	—	39.5	—	39.5	—	39.0	Sl. woody	39.0	—
4B	0.21	6.28	39.0+	Very sl. acid	39.5	—	39.5	—	39.0	Sl. stale	39.0	Sl. stale
4C	0.23	6.10	39.0	Sl. sour	38.5	Sl. metallic	39.0	Indic. sl. met.	38.5	Sl. stale, sl. unc.	39.0−	Sl. stale
9B	0.19	6.14	39.5	—	39.0−	Sl. age	39.5	—	38.5	Sl. tallowy	39.0	—
10B	0.20	6.01	39.0	Indic. sl. met.	38.0	Sl. met., sl. acid	38.0	Sl. met., sl. acid	38.0	Sl. tallowy	38.0	Sl. tallowy
Ave.	0.203	6.10	39.0		38.94		39.10		38.42		38.75	
1C	0.30	5.54	37.0	Met. and unclean	38.0	Unclean, stale	38.0	Sl. metallic	38.0	Unclean, stale	38.0	Storage
2C	0.30	5.56	37.0	Metallic, sour	38.0	Sl. met., acid	38.0	Sl. met., sour	38.0−	Sl. acid, sl. met.	38.0	Sl. met., storage
5	0.30	5.73	39.0	Indic. sl. met.	39.0	Liner	38.0+	Sl. stale	38.0	Sl. tallowy (deg.)	38.0	Sl. stage, degrade
6	0.35	5.35	39.0	Indic. sl. met.	38.0	Sl. met., sl. stale	38.0−	Sl. stale, acid	38.0−	Sl. stale	38.0−	Sl. tallowy
7	0.29	5.35	39.0	Indic. sl. met.	39.0	Liner	39.0	Liner, v. sl. met.	38.5	Sl. tallowy	38.5	Sl. stale
9C	0.30	5.52	38.0	Sl. metallic	38.5	Storage	39.0	Sl. acid	38.0	Tallowy	38.5	Sl. stale
10C	0.32	5.50	38.0	Sl. met., acid	37.5	Metallic, acid	38.0	Sl. met., acid	37.5	Tallowy, fishy tendency	38.0	Tallowy, fishy tendency
Ave.	0.31	5.51	38.14		38.29		38.32		37.79		38.21	

* pH of butter after storage at 12° F.

TABLE 3.—SUMMARY OF CREAM AND BUTTER ACIDITIES AND FLAVOUR SCORES

No. of churnings	Average cream acidities		Ave. pH of butter*	Average flavour scores				
	Titratable	pH		Fresh	After storage at 12° F.		After storage at −10° F.	
					Interior	Surface	Interior	Surface
7	0.116	6.84	6.76	39.64	39.46	39.10	39.57	39.25
8	0.203	6.16	6.10	39.0	38.94	38.42	39.10	38.75
7	0.31	5.55	5.51	38.14	38.29	37.79	38.32	38.21

* After storage at 12° F.

TABLE 4.—COPPER CONTENTS AND PEROXIDE VALUES OF BUTTERS

Churn. no.	Cu. p.p.m.	Peroxide values*			
		Storage at 12° F.		Storage at −10°F.	
		Interior	Surface	Interior	Surface
1A	0.12	0.8	1.2	0.8	1.2
2A	0.12	0.2	0.8	0.2	0.6
3A	0.08	0.1	0.5	0.1	0.3
4A	0.10	0.0	1.3	0.5	0.7
8	0.08	0.8	0.7	0.7	1.3
9A	0.07	0.0	0.1	0.0	0.1
10A	0.09	0.1	0.7	0.1	0.4
Ave.	0.094	0.28	0.76	0.34	0.66
1B	0.09	1.2	1.3	1.2	1.1
2B	0.07	0.8	0.9	0.5	0.8
3B	0.06	0.3	0.3	0.3	0.4
3C	0.07	0.1	0.6	0.2	0.4
4B	0.08	0.7	1.0	0.6	0.7
4C	0.05	0.7	1.3	0.7	1.1
9B	0.05	0.1	0.5	0.0	0.3
10B	—	0.3	—	0.3	0.6
Ave.	0.067	0.52	0.84	0.47	0.675
1C	0.06	1.2	1.2	1.1	1.2
2C	0.09	0.0	1.0	0.7	0.8
5	0.05	0.7	1.0	—	0.9
6	0.07	0.8	1.3	1.0	1.1
7	0.03	0.7	1.0	0.9	1.0
9C	0.12	0.8	0.9	0.6	0.7
10C	0.28	1.2	—	1.0	—
Ave.	0.10	0.90	1.06	0.88	0.95

* No. ml. of .002N sodium thiosulphate per gram fat.

distance is 214 rods and the rise a remarkably gradual one of 134 feet. The ridge at this point is just over 2,500 feet above sea level. Of recent years the slough has been more or less completely drained by highway ditches and has been largely broken and cropped.

PROCEDURE

On July 1, 1926, a self-registering minimum thermometer was hung at the apex of the ridge checking against one previously placed at the slough edge. On May 1, 1927, four similar instruments were placed along the roadside between these extremes at equal successive rises of 26.8 feet, the distances being nearly uniform. All were hung $3\frac{1}{2}$ feet above ground level and were at first uncaged. Slight errors in the instruments marred some of the minor comparisons in the early years and breakages necessitated a temporary curtailment of the intermediate records in 1928. In 1929 the readings of the slough-edge thermometer between June 16 and August 24, inclusive, were discarded as inaccurate.

During the latter part of January, 1930, all six instruments were placed in louvred cages at a height of $3\frac{1}{2}$ feet. This reduced the occasional error from shaking by the wind, and lessened, though it did not altogether prevent human interference. Since April 3, 1930, the records have been interrupted but little. Occasionally a mistake would be made or a violent wind would displace the needle indicator. Any marked discrepancy in the accustomed rhythm led to the discard of the readings for such a day. A departure of 1 or 2 degrees either way was tolerated.

The readings were taken at 1.00 p.m., when the temperature was nearly always above the previous night's minimum. All instruments were occasionally compared with a reliable checking thermometer. All were situated above a grassed fence-bottom. All were on the north side of the road except the fifth from the bottom, which was placed across the road to avoid complications by trees and cultivation. The instrument at the slough-edge was designated as at post No. 1; that on the hilltop as at post No. 6. The first, second, third and sixth instruments had about equally exposed positions. Nos. 4 and 5 may have been slightly affected by artificial heat and shelter, particularly No. 4, which was southeast of the buildings and averaged a shade higher than the relationship of the other readings would lead one to expect.

Comparisons between the slough-edge and the hilltop are available from July 1, 1926, to December 31, 1942, when the readings were discontinued as a measure of wartime economy. Satisfactory comparisons of readings at six points are available from February, 1930, to December 31, 1942.

RESULTS

Since July 1, 1926, accepted comparisons between slough edge and hilltop number 5802 out of a possible 6028. On 1942 nights, which is practically one-third of the total of 5802, the slough thermometer read 10 or more degrees lower than that on the hilltop; on 649 nights, 15 or more degrees lower; on 172 nights, 20 or more degrees lower. On the other hand, on 161 nights of accepted readings the slough thermometer read 1 or more degrees less extreme than that on the hilltop.

Extreme Spreads per Annum

In every one of the 16½ years from July, 1926, to December, 1942, there has been an extreme spread of 23 degrees or more. In 6 years the extreme spread was 24 degrees; in 6 years, 25 degrees; in 2 years it was 26 degrees and in February, 1929, there was a spread of 28 degrees!

Months of Greatest Spreads

In 5 years out of 16, February registered the most extreme spread of the twelvemonth, and once February tied with December. In 4 years, March had the greatest spread; in 3 years, December; in 2 years, November, and only once did the greatest spread occur in January.

TABLE 1.—MOST EXTREME SPREADS PER MONTH FROM 1926 TO 1942, INCLUSIVE REGISTERED BY SELF-REGISTERING MINIMUM THERMOMETERS SITUATED, RESPECTIVELY AT THE FOOT AND AT THE APEX OF A HOG'S BACK RIDGE WITH AN EASTERN SLOPE 214 RODS LONG AND A RISE OF 134 FEET

Year	Most extreme spreads												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Per year
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1926	—	—	—	—	—	—	13	14	15	14	18	24	24
1927	23	25	22	19	14	10	11	15	13	12	17	24	25
1928	22	23	22	16	15	12	13	14	18	15	16	23	23
1929	24	28	22	18	16	—	—	—	13	16	20	18	28
1930	22	23	25	10	13	10	14	14	14	15	21	16	25
1931	20	15	18	13	14	15	14	17	18	16	24	25	25
1932	23	20	24	13	15	13	13	16	18	12	23	22	24
1933	21	19	24	14	9	12	13	15	16	13	18	21	24
1934	26	21	19	15	14	11	12	13	12	11	18	22	26
1935	21	26	24	21	13	12	9	10	16	16	23	19	26
1936	16	23	19	13	17	15	12	14	17	14	21	24	24
1937	21	24	19	21	13	17	16	15	17	14	16	17	24
1938	22	21	14	14	15	13	15	14	13	16	18	25	25
1939	22	20	23	17	11	11	19	15	11	17	13	19	23
1940	21	22	19	11	13	10	10	14	17	16	25	24	25
1941	20	24	22	15	12	11	17	9	9	17	18	22	24
1942	18	16	17	11	12	13	16	15	16	17	25	17	25

Average Monthly Spreads

In a 13-year comparison of mean monthly spreads between hilltop and slough thermometers the widest divergence was 9.26 degrees in February, followed by 8.62 in December, 8.59 in January, 7.85 in March, 7.15 in August and 7.02 in November. June, a month of long days, had the narrowest average spread of 4.97 degrees, followed by April with 5.04; May with 5.15; October with 6.18; September with 6.47; and July with 6.48. For 13 years the average of the monthly means was 6.90 degrees. Thus while the tendency is for the colder months to show the greater spreads such is not invariably the case; nor is the converse unfailingly true of the summer months.

TABLE 2.—COMPARING MONTHLY SPREAD OF AVERAGE MINIMUM TEMPERATURES BETWEEN SELF-REGISTERING MINIMUM THERMOMETERS SITUATED, RESPECTIVELY, AT THE FOOT AND THE APEX OF A RIDGE WITH AN EASTERN SLOPE HAVING A FALL OF 134 FEET IN 214 RODS, FROM 1930 TO 1942, INCLUSIVE

Month	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	Average 13 years 1930-42
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
January	9.16	8.61	8.45	9.00	9.90	8.81	5.53	10.00	9.13	9.21	8.89	7.22	7.78	8.59
February	8.15	8.18	7.14	8.71	7.79	14.46	11.96	11.97	6.96	6.84	9.10	11.54	7.57	9.26
March	11.10	4.26	10.50	12.10	3.67	8.19	7.58	6.22	4.78	8.78	7.44	10.46	6.94	7.85
April	4.15	6.20	3.67	6.00	3.90	7.96	3.86	6.48	5.54	4.60	2.83	6.10	4.23	5.04
May	4.66	6.87	5.71	3.69	5.26	4.30	5.17	5.76	7.30	5.00	5.51	3.83	3.84	5.15
June	2.52	5.45	7.93	3.85	4.42	4.04	5.38	7.27	5.20	4.35	4.70	4.90	4.64	4.97
July	8.40	7.49	6.52	5.53	5.60	4.23	5.36	8.13	7.39	5.93	4.80	6.42	8.44	6.48
August	8.24	9.03	6.23	8.86	6.00	4.94	6.94	6.97	5.10	8.36	8.87	4.16	9.26	7.15
September	6.00	6.67	8.96	5.68	4.03	5.60	7.73	8.00	7.04	5.46	9.70	2.63	6.60	6.47
October	4.65	8.52	5.71	5.80	4.68	6.80	5.56	5.23	6.00	4.77	8.00	6.27	8.30	6.18
November	5.74	10.43	7.33	4.07	5.97	7.21	8.25	5.23	8.07	6.17	8.20	7.17	7.44	7.02
December	8.13	9.23	12.03	6.93	11.31	5.49	7.29	5.23	9.58	9.23	11.93	9.32	6.37	8.62
Average														6.90

TABLE 3.—COMPARING 13 AVERAGE YEARLY MEANS (1930-1942) OF MINIMUM TEMPERATURES REGISTERED BY CAGED SELF-REGISTERING MINIMUM THERMOMETERS PLACED AT EQUAL SUCCESSIVE RISES ON A GRADUAL EASTERN SLOPE WITH A TOTAL ASCENT OF 134 FEET IN 214 RODS

Year	No. I	No. II		No. III		No. IV		No. V		No. VI		Spread between highest yearly mean and lowest yearly mean of I and VI
	Slough temp. yearly mean	Temp. yearly mean	Degrees above (+) below (−) No. I	Temp. yearly mean	Degrees above (+) below (−) No. II	Temp. yearly mean	Degrees above (+) below (−) No. III	Temp. yearly mean	Degrees above (+) below (−) No. IV	Temp. yearly mean	Degrees above (+) below (−) No. V	
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
1930	*24.44	*27.24	2.80	*28.91	1.67	*30.04	1.13	*30.35	0.31	*30.96	0.61	6.52
1931	21.37	24.74	3.37	26.51	1.77	27.89	1.38	28.33	0.44	28.98	0.65	7.61
1932	16.18	19.39	3.21	20.91	1.52	22.25	1.34	22.70	0.45	23.70	1.00	7.52
1933	14.39	17.20	2.81	18.41	1.21	19.81	1.40	20.44	0.63	21.07	0.63	6.68
1934	21.73	24.16	2.43	25.49	1.33	26.78	1.29	27.21	0.43	27.77	0.56	6.04
1935	17.98	20.92	2.94	22.31	1.39	23.88	1.57	24.15	0.27	24.81	0.66	6.83
1936	17.39	20.16	2.77	21.72	1.56	23.07	1.35	23.67	0.60	24.11	0.44	6.72
1937	17.65	20.71	3.06	22.17	1.46	23.66	1.49	24.45	0.79	24.85	0.40	7.20
1938	21.36	23.79	2.43	25.25	1.46	26.84	1.59	27.80	0.06	28.21	0.41	6.85
1939	21.30	24.03	2.73	25.35	1.32	26.71	1.36	27.57	0.86	27.86	0.29	6.56
1940	19.33	22.28	2.95	23.94	1.66	25.43	1.49	26.41	0.98	26.83	0.42	7.50
1941	21.85	24.47	2.62	26.00	1.53	27.37	1.37	28.25	0.88	28.51	0.26	6.66
1942	21.51	24.04	2.53	25.55	1.51	27.15	1.60	27.82	0.67	28.30	0.48	6.79
Average	19.73	22.55	2.82	24.04	1.49	25.45	1.41	26.09	0.64	26.61	0.52	6.88

* Average of 11 months, February 1 to December 31.
Average spread calculated horizontally.

Spreads Decrease Towards the Top

The tendency is for the spreads to decrease as one ascends the slope. Thus in the course of 13 years, 1930 to 1942, inclusive, the second post has averaged 2.82 degrees less extreme than post No. 1, situated at the slough edge. The third post is 1.49 degrees milder than the second; the fourth, 1.41 degrees milder than the third; the fifth, 0.64 degrees milder than the fourth, and the sixth, 0.52 degrees milder than the fifth. The spread between posts 1 and 6 figures out to be 6.88 degrees (which differs by two one-hundredths from the figures arrived at where monthly spreads are averaged.)

Several factors may be suggested to explain the decrease in spreads towards the top. The cold air builds up from the bottom towards the ceiling of the inverted temperature, the cold being most intense at the bottom. The basin widens upwards and a given volume of cold, so to speak, may depress the narrower horizon of air by more degrees than it would affect the wider horizon above. In other words, a given volume of cold air will fill a narrow basin fuller then it would fill a wide one.

Frost-free Periods Hilltop and Slough

The practical importance of the study is emphasized by a comparison of frost-free periods at the slough edge and hilltop for 11 years, 1932 to 1942, inclusive. The frost-free seasons at the hilltop (32° being taken as frost) ranged from 66 days in 1935 to 129 days in 1940, averaging 106. At the slough there was frost every 10 days in 1933, and the longest frost-free period was 76 days, in 1941, the 11-year average being only 32 days Thus the frost-free period at the hilltop averaged *more than three times as long as at the slough.* At the slough frost occurs in every month of the

TABLE 4.—LONG-TIME RECORD OF LAST SPRING AND FIRST AUTUMN FROSTS AT SLOUGH AND ON HILLTOP, 32° F. BEING TAKEN AS FROST

—	Hilltop			Slough		
	Last frost in spring	First frost in fall	Frost-free season	Last frost in spring	First frost in fall	Frost-free season
			dy.			dy.
1932	June 18	Sept. 12	85	Aug. 6	Aug. 31	24
1933	June 11	Sept. 4	84	Frost recorded every ten days		10
1934	May 22	Sept. 12	112	July 19	Aug. 1	12
1935	June 8	Aug. 14	66	July 4	Aug. 14	40
1936	May 12	Sept. 10	120	June 13	July 12	28
1937	May 28	Sept. 21	115	July 11	July 27	15
1938	June 6	Sept. 29	114	June 9	July 31	51
1939	May 10	Sept. 13	125	July 13	Aug. 16	33
1940	May 28	Oct. 5	129	June 29	Aug. 4	35
1941	May 26	Aug. 30	95	June 14	Aug. 30	76
1942	May 15	Sept. 14	121	June 26	July 26	29
	Average		106	Average		32

N.B.—In computing the number of frost-free nights between, it is to be borne in mind that if the last spring frost occurs on, say, June 9, there will be 22 June nights free of frost while if the first fall frost occurs August 31, there will be only 29 August nights free of frost the reading of morning of August 1 being counted as for the night of July 31.

average year; on the hilltop roses have not infrequently bloomed in October and once as late as November. In 1943 on the hillside a perfectly good windfall apple was picked up on November 12.

It should be understood that a light frost is not necessarily lethal even to tender crops and that some crops will be little if at all injured by several degrees of frost. Thus even after allowance is made for the fact that the temperature at grain level may be lower than the temperature indicated by the caged thermometer, the fact remains that the Peace River region as a whole is a much safer cropping region than this data might suggest.

DISCUSSION

During rain or snow storms there has been no difference in the readings of the respective thermometers. Once during a slow 2-day summer rain the Station's official thermometer was observed to hover around 34 to 36 degrees F., without any sign of frost at the ground level there or at the slough. In humid, cloudy weather, even without rainfall, there is little difference. Clouds check radiation and guard against inversion of temperature.

Wind, mixing the air as it does, diminishes but does not always eliminate temperature spreads. Several degrees of difference sometimes persist in winter for days with more or less air motion in progress. On one occasion a cold wave sweeping in towards sunrise of an autumn morning brought a brief touch of frost to the hilltop without any more (if indeed any whatever) at the slough basin. This, though, was very exceptional. In some years wind has been remarked as having a predominant influence in restricting spreads, while in other years it has seemed a less important factor.

While there is a tendency for the colder months to exhibit the wider spreads and the warmer months the lesser spreads this does not hold uniformly, by any means, even when long-term averages are considered, and decidedly not when individual years are considered. Other factors, such as precipitation, clouds and wind, enter into the picture. During 13 years the greatest mean spread occurred not in the coldest month of January but in February, while the least average spread occurred in June, rather than in the hottest month, July.

February, March, December, November, and January hold the honours in this order for the greatest number of extreme spreads per annum.

The greatest spread has seldom been found on the coldest nights but rather when a cold snap was relenting, the hilltop experiencing the change first, while a blanket of cold air lay in the slough. Marked spreads may also occur with the second or third night of clearing weather following a storm. The greatest recorded spread of 28 degrees occurred on February 19, 1929, when the weather was moderating after a cold spell, the respective readings being -30 and -2. In 1932 it was observed that the year's greatest spread of 24 degrees occurred on March 15, after a fall of snow but not on an extremely cold night.

In 1935 the greatest spread, of 26 degrees, occurred not in the bitter-cold month of January but in the comparatively mild, calm month of February, on a moderate night and after a period of mild winter weather.

In 1936 the widest spread was 24 degrees on December 19, when readings were −13 and +11, while the second-widest spread that year was in February, when the comparative readings were −50 and −27. It would seem that, as with the Peace climate in general, the most regular feature is irregularity.

While no maximum readings and therefore no daily means have been registered, it has often been observed in the reading of the instruments that in summer the mid-day temperature might be as high at the slough as on the hilltop and sometimes higher. In winter it was rarely higher and was not infrequently lower in the slough.

The data is not only important from a climatological point of view but has a profound ecological significance. The frost-free period at the slough averaged only 32 nights. On the hilltop it was 106 nights. In 1933 it was roughly conjectured from 3 years' comparative data that there was probably more ecological difference between the slough and the hilltop than between Beaverlodge and Lethbridge, 380 miles farther south (though 539 feet higher than the 2444 feet which represents an average of the slough and the hilltop at Beaverlodge). Whether this comparison would hold absolutely over a long term is difficult to establish with the data at hand, but it seems likely to approximate the truth. Climatologists and ecologists are warned that the situation of a given set of meteorological instruments should be carefully regarded in the interpretation of its data.

The undulating contour of the Peace River region and the air drainage afforded by its numerous deep ravines increases its adaptability to crop production, since the high land may in many instances be chosen for residences, gardens and tender crops while frost-hardy crops such as hay, greenfeed, and, to a lesser extent, oats for threshing may be raised in the frostier areas.

SUMMARY

The Beaverlodge Experimental Station is situated on the eastward slope of a ridge tapering southward, bordered on the east by a frosty horseshoe-shaped slough-basin which receives air drainage from all directions except the southeast, where it has a flat, scrub-fringed outlet. An east-west highway ascends the slope along the front of the Station premises, with a gradual rise of 134 feet in 214 rods. At the slough-edge and at the apex of the ridge, minimum self-registering thermometers placed along the roadside were read daily from July 1, 1926, to December 31, 1942, while 4 intermediate thermometers, placed at equal successive rises, were read without serious interruption by accidents from February, 1930 to December, 1942, inclusive.

Since July 1, 1926, there were 5802 days of readings accepted as trustworthy. On 172 nights (nearly 3%) the slough-edge thermometer read 20 or more degrees lower than the one on the hilltop. As much as 28 degrees difference has been recorded, and the average spread has been nearly 7 degrees Fahrenheit.

In the 13 years, 1930-42, February had the widest mean spread (9.26 degrees) of any month, and June the least (4.97 degrees). While the colder months showed the greater ruling spreads, this was not rigidly true.

Ascending the slope, the spread in readings decreased steadily with occasional exceptions, probably attributable to the influence of adjacent buildings. The average spread between 1 and 2 was 2.82 degrees; between 5 and 6, only 0.52 degrees.

Greatest spreads usually occurred when a cold snap was relenting and on the second or third clear night following a storm. Other things equal, spreads were most marked on calm, clear nights. Rain, snowstorms, clouds and humidity appeared to reduce or eliminate them. Wind reduced but seldom eliminated them.

Preliminary readings had shown that thermometers caged $3\frac{1}{2}$ feet above a lawn might register nightly minima several degrees above uncaged ones at the same level, while the latter in turn might register as much as 8 or 10 degrees above uncaged ones at the ground. Subsequent data has shown that such differences coincide with sharp differences between hilltop and slough readings.

In summer the 1.00 p.m. readings appeared to average quite as high at the slough as on the hilltop and were sometimes higher. In winter, inversion of temperature might persist in some degree throughout the 24 hours, though not always.

If a caged-instrument reading of 32° F. be taken as frost, the 11-year average frost-free period at the slough was only 32 successive nights, whereas on the hilltop it averaged 106 nights, and roses have bloomed there in November. Thus between these two points a little over half a mile apart and 134 feet different in local elevation there is probably nearly as much ecological difference as between Beaverlodge and Lethbridge, 380 miles farther south.

Undulating contour in a boreal region increases adaptability by fitting the high land for residences, gardens, tender crops and seed grain, while the low land may successfully grow fodder.

The topographical situation of any given set of weather instruments should be carefully regarded in the interpretation of its data.

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THE EFFECTS OF SUBZERO TEMPERATURES ON *HYPODERMA LINEATUM* DEVILL.[1]

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The importance of the two common North American Warble flies, *Hypoderma lineatum* DeVill. and *H. bovis* Deg., has been greatly increased in recent years. Wartime conditions have made it necessary to carry on extensive campaigns to control these pests. Serious gaps in our knowledge of their biology have hampered control and eradication measures, and it is therefore the purpose of this paper to close one gap by presenting factual data on the effects of subzero temperatures on *Hypoderma lineatum*. Similar studies dealing with *H. bovis* are not considered necessary, since the grubs of this species drop too late in the season to be in danger of freezing.

Heretofore it has been thought that warble grubs and puparia were fairly resistant to low temperatures. Bishopp *et al.* (1) reported observations on the exposure of small numbers of larvae and pupae to temperatures of 7, 9.5, 19, and 25 to 29 degrees F. Most of the material survived, and it was concluded that "Mature larvae and pupae can withstand rather low temperatures." While this was a statement of considerable importance, the evidence was sketchy, and the need of precise data remained. The need was a practical one, for in the colder areas of the insects' range stockmen were worried about the time of the first spraying of their stock. Large herds are now sprayed with a water suspension of derris and wettable sulphur under high pressure, and if the weather is cold or likely to turn cold, spraying is not so likely to be carried on. In the meantime, grubs are maturing and some may be dropping from the animals' backs. Two problems are crucial here. First, do mature grubs actually drop during cold weather or even before the danger of cold weather is past, and to what extent? Second, what temperatures can dropped grubs survive, and to what temperatures are they likely to be subjected? Only the second of these problems is discussed in detail here, but a few observations are presented which bear on the early dropping of grubs.

MATERIAL AND METHODS

Practically all of the mature grubs and puparia used in these studies were obtained from the Livestock Insects Laboratory at Kamloops, B.C., through the coutesy of J. D. Gregson and G. P. Holland; the remainder were obtained at Lethbridge, Alberta. Larvae were kept on ice for the short period before they were frozen; puparia were kept at prevailing outside temperatures and were frozen at ages of 1 to 23 days. All larvae and puparia were frozen in the same thermocouple holder, which was constructed of rubber and glass (Salt (2)). A copper-constantan thermocouple and a sensitive galvanometer allowed continuous reading of the temperature to an accuracy of 0.1° C. or better. The freezing chamber was kept at a constant temperature of −30° C. throughout the experiments. The rate of cooling of all specimens was therefore the same, being about 2.5° per

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minute at 0° C.; 1.0° per minute at −13° C.; 0.5° per minute at −20° C.; and 0.25° per minute at −24° C. Larvae and puparia frozen in a wet condition, to test the effects of contact moisture, were either dipped into water and the excess shaken off, or soaked between layers of damp cellucotton for several hours.

RESULTS

Although the number of larvae and puparia used was fairly small, the results of the individual freezings were sufficiently consistent to give reliable data. Specimens were frozen both dry and wet, the latter to determine whether or not contact moisture would seed or inoculate the tissues and thereby lessen undercooling. Table 1 summarizes the results for 19 mature, normally-dropped, active larvae.

TABLE 1.—UNDERCOOLING POINTS FOR *Hypoderma lineata* LARVAE

Dry		Wet	
No. 5	−24.7° C.	No. 7	−24.4° C.
14	−24.7	9	−17.7
17	−24.7	10	−24.4
18	−23.9	11	−24.0
19	−25.2	12	−23.0
20	−22.7	13	−24.0
21	−19.8	15	−25.0
22	−21.1	16	−25.7
		23	−23.0
		24	−23.2
		25	−21.9
Mean	−23.4 ± 2.0° C.	Mean	−23.3 ± 2.1° C.

Combined Mean 23.3 ± 2.0° C.

Contact moisture had no effect on undercooling of the larvae. All larvae died on being frozen, even if removed from the freezer within a few seconds after the rebound started. The lethal temperature range of dropped larvae, whether wet or dry, is therefore the undercooling range, as represented by Table 1.

The corresponding experiments with puparia gave similar results. Age of the puparia, however, was taken into consideration. Each specimen, also, was carefully opened after freezing to determine its stage of development and to see if the contained larva or pupa had been alive (in all probability) before freezing. Table 2 summarizes the data on puparia.

TABLE 2.—UNDERCOOLING POINTS OF *Hypoderma lineata* PUPARIA

Larval Age 1-2 days	Pupating Age 4-5 days	Pupal Age 20-23 days
No. 1 dry −24.0° C.	No. 7 dry −20.1° C.	No. 9 dry −24.8° C.
4 dry −23.7	8 dry −19.9	10 wet −24.4
5 dry −22.2		11 wet −23.9
		12 wet −25.2
		13 dry −24.9
		14 dry −24.6
		16 wet −25.0

Combined Mean 23.6 ± 1.8° C.

Again contact moisture had no effect on undercooling, so it may be ruled out as a factor with this species. The undercooling range is practically the same as for the larvae, but less undercooling is noted in the two specimens which were in the act of pupating. Freezing was fatal to the puparia, as it was to the larvae.

Tables 1 and 2 show how low the temperature must drop before the larvae and pupae freeze and die. What temperatures are they likely to encounter in nature? The answer of course varies with the locality. A series of temperature readings was made in the Lethbridge district from February 15 to March 31, 1944. Readings were taken with a portable thermocouple-potentiometer and a copper-constantan thermocouple especially adapted for penetrating soil, manure, straw, etc., where these materials were not packed too hard. Although the pertinent temperatures were those on the surface or just under, readings were made to depths as great as 10 inches in the straw and manure of feed-lots, and down to hard material in other locations. A series of readings was taken during and soon after cold spells, and included outside locations where grubs were likely to drop, e.g., pasture, corrals and feed-lots.

In feed-lots, where straw and manure are deep, temperatures did not drop below freezing except on the surface. On the other hand, there was no danger of overheating if larvae burrowed down into this relatively soft material. In corrals, temperatures varied according to the hardness of the soil, which in turn was tied up with the amount of straw and manure present. The weather was relatively open throughout the entire period, with no snow sufficient to cover the ground except from February 28 to March 7. Snow was of little value as cover in corrals and feed-lots, as it soon was packed down and mixed with straw and manure. Much of it was melted by manure and by animals lying down on it. In open pasture, however, snow may be of considerable value as an insulator against low temperatures.

The results of this series of temperature readings, along with minimum and mean air temperatures, snow cover and the undercooling range, are shown in Figure 1. The readings are shown beneath the snow-cover figures, and represent the range of temperature readings from soil surface to a depth of 1 inch, and from snow surface to soil surface. All temperatures in the figure are on the more familiar Fahrenheit scale. The lowest temperature recorded was 8.6° F. (-13° C.) at a point $\frac{1}{4}$ inch above the soil surface, which had a fine semi-covering of snow. This reading was taken in pasture; in corrals and a feed-lot nearby the temperatures were higher.

In the vicinity of Lethbridge, during the crucial period from February 15 to March 31, 1944, warble grubs and puparia were in little danger of freezing. Although the leeway may not seem great, it is considered sufficient, especially in view of the lack of protective snow cover this year. In addition, very few individuals would freeze at 0° F., the mean undercooling point being 10 degrees lower.

The problem remains, however, to find the extent to which grubs are dropped before cold weather is past. The observations presented here are admittedly meagre, but indicate that the majority, if not all, of the earliest

dropped grubs are immature. Stockmen and technical men alike have noticed that very early in the season (February and early March in southern Alberta), white larvae, apparently full-grown, are often found stuck to the hair of infested stock or protruding partly from the emergence hole, encased in a considerable amount of pus. Usually these immature forms are dead

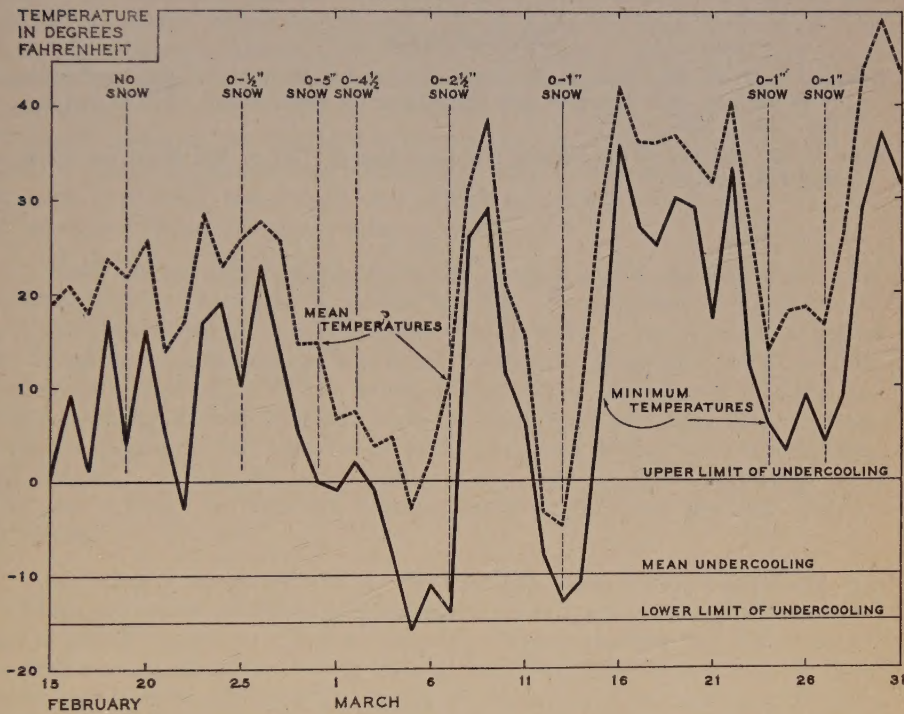

FIGURE 1. Minimum temperatures, snow cover, and undercooling range.

when found, but several living specimens were taken to the laboratory and kept to see if they would mature. All of them died within a day or two. Four others were frozen soon after removal from the backs of animals where each was found stuck in the hair. Their undercooling points were -9.8, -10.5, -14.6 and $-5.7°$ C. These temperatures are dangerously high, but in view of the facts that the larvae was fastened securely to the hair, were immature, and seemed unable to mature, the danger of freezing is probably unimportant.

Fully mature grubs have not been observed by the author dropping before the danger of cold weather is past, but this may easily be the result of chance, as mature grubs are rarely seen emerging in any case. On the other hand, the white immature larvae that get stuck in the hair are readily seen. Finding an empty cyst may therefore mean the emergence of either a mature grub or an immature grub.

CONCLUSIONS

In southern Alberta there is little chance that early dropped warble grubs will be frozen and killed. To the stockmen this means that early spraying may be necessary. However, there are indications that many, if not all, of the early dropped grubs are immature forms, and that these are incapable of maturing. Further study of this aspect of the problem is of urgent practical importance.

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BOOK REVIEW

FOOD ENOUGH. John D. Black, The Jaques Cattel Press, Lancaster, Penn. 1943. 269. pages. $2.50.

Action in the Pacific Area in 1942 brought the food problem into bold relief. A situation that had been changing gradually for a year or two became a matter of serious concern. Food made the headlines and a good deal was written on the subject—some of it critical. In the United States acute shortages were predicted and the policies of the Department of Agriculture were subjected to criticism. Dr. Black, Professor of Agricultural Economics at Harvard takes his cue—and his statistics—from the United States Department of Agriculture, and in the words of his publisher, lays "a reassuring hand upon our troubled brows to clarify our thoughts in regard to the entire production picture."

Food Enough is a book for both the layman and those who want their information buttressed by facts and figures. It is written in popular style but contains as much factual and statistical data as many texts designed for those with an analytical and scientific bent. Beginning with the food situation in general, with the needs of the armed forces, war workers and other civilians, it then proceeds to deal with Allied and enemy food supplies, with manpower and machines, with rationing shifts, in consumption, production possibilities, relief requirements and the food situation after the war. These matters are treated under twenty-one separate chapter headings.

Included in the chapters on the feeding of the armed forces and war workers are some interesting statements on nutritional requirements and the effect of organized effort to improve dietary standards. The chapter on civilian consumption reveals that though but three-quarters of the food produced is now available for civilians, no general reduction in civilian consumption has taken place. The reason of course is a greatly increased output.

Thirty-two countries draw supplies from the United States under Lend-Lease Arrangements but the major part of lend-lease transfers has gone to Great Britain and Russia. Cash sales to lend-lease countries to January 1, 1943 were greater than lend-lease exports. In the first year 47% of lend-lease shipments were food but since then the proportion has dropped to 20%.

Quoting the Office of Foreign Agricultural Relations, United States Department of Agriculture, Dr. Black indicates that the food supplies of Continental Europe in March 1943 were 15% below pre-war. The greatest reductions are thought to have occurred in swine and poultry production. The production of cereals, potatoes and other vegetables has been increased to offset meat shortages. German consumption in terms of calories, probably the highest in enemy or occupied countries, is estimated at 85 to 90% of pre-war, while Greece, at the other extreme, dependent to a large extent upon imported food, has experienced acute shortages.

In this book Dr. Black has capitalized on current interest in the food situation but he has done much more than deal with food as an article of consumption. His treatment of the subject extends from production problems to nutritional standards, and from pre-war programs to post-war planning.

Among the various matters dealt with, the discussion of prices will probably be among the most interesting to Canadian readers. While the author does not deal extensively with pre-war prices policies he does refer to them. And he discusses the price policies of the war period somewhat more extensively and critically. In his concluding chapter dealing with Food After the War he makes a statement on this matter that will be of particular interest to Canadian farmers in view of the price support legislation already enacted in this country. Dealing with United States experiences, Dr. Black states:—

> "If we have learned nothing from our attempts to help agriculture since 1933, we shall proceed at once to put bottoms under prices of farm products and to move the 'surpluses' into the 'ever normal granary'; and to keep that granary from getting over full we shall establish 'marketing quotas' for all non-perishable products. And then we shall sit and wait for industry to get going again.
>
> "But if we have learned wisdom from our experiences, we shall not look at the declining prices of foods but at their declining consumption, and we shall set about developing an efficient organization and procedure for moving enough of all foods into consumption to restore food prices to a working level."

J. F. Booth.